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Errata.

Page 4, 5 lines from end, for " insecticidal change " read " insecticidal charge "
Page 82, line 7, for " I " read " II "
Page 149, Table V, insert numbering of pens 7–12 above second half of table and below top half
Page 170, 9 lines from end, for " observed " read " obscured "
Page 441, legend to fig. 1, for " Fie " read " Field "

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FACTORS INFLUENCING THE INTERACTION OF INSECTICIDAL MISTS AND FLYING INSECTS.

Part II.—The Production and Behaviour of Kerosene Base Insecticidal Spray Mists and their relation to Flying Insects.*

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* This paper, together with others in the series, represents a thesis approved for the Degree of Doctor of Philosophy in the University of London.

Introduction.

Much attention has been devoted to the design of equipment in which the action of insecticidal spray mist on flying insects can be investigated. Of the large number of techniques which have been suggested that of Peet and Grady (1928) is probably the best known, since in a modernised form (Soap Blue Book, 1943) it has been adopted in the U.S.A. by the National Association of Insecticide and Disinfectant Manufacturers as the official method of standardising household insecticide sprays. In the Peet-Grady test, as in all laboratory methods involving the use of fairly large spray chambers, Richardson (1931), Potter and Hocking (1939), David (1946), and in the practical application of sprays the insecticide is atomised and the droplets formed reach the insects after passing through the intervening air space. It is the purpose of this paper to consider the factors which come into play during the atomisation of the spray and before the mist finally reaches the insects. With the exception of the work of Burdette (1938) and Potter and Hocking (1939), very little attention has been given to the behaviour of atomised kerosene base insecticidal spray mists. The former author considered those droplets which could be collected on plates exposed to the spray mist and within this limitation reached many interesting conclusions. Potter and Hocking developed a method for sampling sprayed atmospheres on the assumption that an organic dye would behave in essentially the same manner as a non-volatile insecticide and they used this technique to investigate the rate of loss of insecticide from the air space under various conditions. The method which they developed has been applied in conjunction with others to the present investigation.

Theoretical Discussion.

1. *The Factors concerned in the Atomisation of the Spray.*

As a preliminary to the study of the behaviour of the spray mist, attention may be directed to the several factors concerned in its production.

Since the methods employed to achieve atomisation vary in spray guns of different design, the relative importance of the several factors which are known to influence atomisation are also likely to change, and for the purpose of the present discussion only the type of atomiser in which the spray is drawn up from the reservoir by the partial vacuum created by the air current at the nozzle is considered. The gun actually employed was the Aerograph M.P. type paint spray gun fitted with a standard three inch extension and a No. 1 nozzle. Two important modifications were made to this atomiser: the gravity feed cup was replaced by a bent piece of narrow gauge brass tubing which dipped down into the spray reservoir so that the liquid was drawn up by suction developed at the nozzle, and the trigger (controlling the air supply and the needle which closed the liquid flow jet) was permanently set back in order to avoid wear and tear on the nozzle during constant use. These modifications in turn made it necessary to control the air flow by a tap on the air feed line (*see* fig. 3, David, 1946). The various physical factors which influence the degree of atomisation attained are considered separately below.

(*a*) *The Design and Dimensions of the atomising Nozzle.*

The size and shape of the air and liquid apertures and their relative positions at the nozzle are the fundamental features determining the degree of atomisation achieved. If the performance of the gun is to remain constant small changes in the size of these apertures and their relative positions due to wear and tear must be guarded against.

(b) The Spraying Pressure and the air/liquid Volume Ratio.

In the Aerograph M.P. gun, atomisation depends upon the impact between the liquid and air jets. When a liquid strikes a surface, which in the case of the gun under consideration is the air jet, it begins to extend, and if the force of impact is sufficiently great it goes on stretching until the tension developed is greater than the surface tension. At this point the liquid breaks up into droplets.

The air pressure determines the amount of energy available for dispersing the spray. As the spraying pressure is increased, the spray becomes more finely divided, also as the air/liquid volume ratio is increased, by restricting the liquid flow, the particles produced become smaller since the amount of energy available per unit volume of liquid becomes larger.

(c) The Viscosity of the spray Fluid.

The viscosity of the spray fluid influences the degree of atomisation attained in two ways. An increase in viscosity leads to a decrease in the rate at which the liquid stretches under impact and it hinders the effect of surface tension in breaking the extended liquid into drops. Thus an increase in viscosity would, in itself, lead to the production of larger spray droplets, but in practice the rate of flow through the liquid feed tube may be so much reduced by this same factor that the direct effect of the increased viscosity may be largely counteracted by the increase in the air/liquid volume ratio. Under these circumstances the output time of a given volume of spray from the gun increases with viscosity. When the rate of liquid flow is kept constant a progressively higher spraying pressure is of course required in order to maintain the same degree of dispersion as the viscosity of the spray fluid increases.

(d) The surface Tension of the spray Fluid.

When the surface tension of the spray fluid is high more energy is required to extend the liquid and cause it to break up into droplets. For example, water, the surface tension of which is about 72·8 dynes/cm. at 20°C., is much more difficult to atomise than kerosene which has an approximate surface tension of 25-30 dynes/cm. at 20°C. Likewise the addition of a surface tension reducing agent to water decreases the amount of energy required in order to attain a given degree of dispersion.[1] It seems rather doubtful whether the surface tension of insecticidal solutions of toxic ingredients and adjuvants in kerosene will differ appreciably from those of the kerosene base.

(e) The Density of the spray Fluid.

In itself a low density favours dispersion since less energy is consumed in bringing about the subdivision of the liquid into scattered droplets. The influences of changes in density on the degree of atomisation are, however, very small.

Thus it can be seen that the degree of atomisation attained is dependent upon many factors including the design of the gun, its working conditions and the properties of the spray fluid. It is usually impossible to change any one factor without bringing about concurrent changes in other aspects of the total situation.

2. *Factors concerned during the Passage of the spray Droplets through the Air.*

The factors that influence the cloud of spray droplets of varying diameter which leaves the spray gun nozzle can be envisaged in two main groups.

(i) Intrinsic factors which are determined by the physical and chemical properties of the liquid sprayed.

(ii) Extrinsic factors which are an expression of the state of the environment through which the droplets pass.

In practice the intrinsic and extrinsic factors interact in a complex manner and in order to avoid repetition these two aspects have not been separated in the following discussion. The several factors, or groups of factors, which influence the behaviour of the droplets in the cloud of spray are considered separately below.

(a) *The Chemical Composition of the Droplet.*

The ultimate behaviour of a spray droplet is determined in several important respects by its chemical composition. In the case of droplets of pure substances the chemical composition is bound up with the density and so the rate of precipitation, and with the volatility which determines the rate of evaporation. In very minute droplets the structural shape of the molecule also will influence the outline of the droplet surface. With pure substances there will be no change of composition during evaporation, except in the case of hygroscopic nuclei (Twort and others, 1940). On the other hand, the rate of evaporation of the several constituents of a solution may be very different so that a few minutes after formation the composition of the droplet may be very unlike that of the solution in the spray gun reservoir.

In the case of insecticidal solutions containing toxic materials and adjuvants, the influence of evaporation on composition will depend on the relative volatilities of the kerosene and the other constituents. Kerosene droplets evaporate rapidly in warm air at dosage volumes below about 15 c.c./1,000 cu. ft. Materials such as pyrethrins, 2, 2-bis (parachlorphenyl) 1, 1, 1-trichlorethane (DDT), sesame oil and isobutylundecylenamide have very low volatilities so that the concentration of these materials in kerosene spray droplets will increase as evaporation takes place. It is interesting to note as well that certain substances of low volatility and solubility are precipitated within the droplets upon evaporation. This can be readily seen with dyes. On the other hand the rate of evaporation of kerosene base insecticidal droplets is no doubt progressively retarded by the operation of two factors. Firstly, since kerosene is a mixture of substances and has a fairly wide boiling point range the more volatile constituents will evaporate first leaving behind the ingredients of lower vapour pressure. Secondly, the vapour pressure of the solutions will be progressively depressed as the concentration of the non-volatile ingredients increases.

(b) *The Size of the Droplet and the Influence of Evaporation.*

Preliminary observations indicate that the sizes of the kerosene droplets produced by an atomising gun of the type under consideration vary within the size range 0·5-50μ. The limits are difficult to determine since the particle size distribution of the mist originally produced is changed rapidly by evaporation and precipitation. From a knowledge of the size of the particle produced and the volume of spray atomised the theoretical number of droplets per unit volume of treated atmosphere can be readily calculated. Since, however, the droplets are not all of one size and are rapidly evaporating only limiting values may be determined in this way. Nevertheless such calculations can provide some indication of the state of the atmosphere to which the insects are exposed in spray chambers, and the relevant figures are given in Table III. From the figures quoted it may be noted that, for instance, one droplet 50 microns in diameter is equal in volume to 1,000 droplets 5 microns in diameter and, therefore, in the case of an insecticidal spray, that the former would carry 1,000 times as much toxic principle. But it is inaccurate to assume that the insecticidal change per droplet is related to its size except at the moment of formation since by evaporation the 50 micron droplet can, in theory at any rate, and probably in practice, give rise to a 5 micron droplet 1,000 times as concentrated as the spray originally injected. The age of the droplet and opportunity to evaporate must be taken into account.

As has already been stated the droplets suspended in the air at any given moment are evaporating whilst they are falling under the influence of gravity. It is therefore pertinent to enquire at what theoretical rates these two processes proceed in order that their relative importance in bringing about changes in the particle size distribution of the mists may be assessed.

Regarding the laws that govern the rate of evaporation of droplets it has been shown by various workers (Langmuir, 1918; Whytlaw-Gray and Patterson, 1932) that as a droplet diminishes in size, the rate of evaporation increases and that this effect is due to the comparatively steeper vapour concentration gradient round the smaller droplet as well as the increase in the ratio of surface to volume. In other words as evaporation takes place the number of molecules that leave a unit area of surface in a given time increases since the vapour concentration gradient becomes progressively steeper as the droplet diminishes in size. This progressively increasing rate is already evident in droplets evaporating from one or two millimetres in radius downwards.

A droplet evaporating according to the principles just discussed will be influenced by many factors. For example the rate of evaporation will be depressed by the partial saturation of the surrounding atmosphere with the material evaporating. Thus the saturation concentration of odourless kerosene in air at 28°C. is of the order of 50 gms. per cubic metre (the value would be between 100-150 gms. per cubic metre for average partly refined kerosene; data kindly supplied by the Asiatic Petroleum Co.). Fly sprays are commonly applied at dosages of about 55 c.c. per 1,000 cu. ft. (Peet-Grady Test) or less, which is very far below the saturation concentration. Yet even well below this volume dosage (*i.e.*, about 10 c.c./1,000 cu. ft.) the persistence of the droplets is appreciably influenced by the volume of spray applied (*see* Tables XIII, XIV and XVII).

As has already been stated the vapour pressure of the spray droplets is subject to depression as the more volatile constituents evaporate preferentially but in the droplet size below 0·1 micron radius certain additional factors come into play. In this region both the radius of curvative of the droplet and the electric charge on the surface begin to influence the vapour pressure: the former to increase it the latter to depress it. For example the vapour pressure of droplets of water radius $1 \cdot 6\ \mu\mu$ ($1\ \mu\mu = \frac{1}{1000}$ micron) at 0°C. is twice that at a plane surface (Gibbs, 1924). When, however, it is realised that the time of evaporation of a 10 micron radius odourless kerosene droplet is only about 0·3 sec. at ordinary temperatures, it will be recognised that the factors involved are hardly likely to be of any practical significance from the point of view of insecticidal sprays. In passing, it may be noted that it is, however, quite conceivable that the presence of an electric charge on the surface of a spray droplet may have some importance in determining the quantity of insecticide accumulated by an insect during a flight through the mist according to whether the mist droplets and the insect are carrying similar or opposite charges. This question would seem to warrant further investigation since it has been shown by De Broglie (quoted by Gibbs, 1924) that when a liquid is atomised in air the increase in specific surface is usually associated with electrification of the particles, although certain substances, *e.g.*, benzene, apparently produce neutral droplets.

While a 10 micron radius water droplet evaporates in 0·06 seconds in still air at 18°C. (Whytlaw-Gray & Patterson, 1932), the times taken by odourless kerosene droplets to evaporate at 28°C. are about thirty seconds for a 100μ diameter droplet and 0·3 seconds for a droplet 10μ in diameter. In practice, however, droplets of insecticide would take appreciably longer due to the depression of the vapour pressure of the kerosene by the non-volatile insecticidal ingredients present and to the existence of an appreciable concentration of vapour around the droplets in the chamber.

(c) The Rate of Movement of the Droplets.

Consider the droplet as it leaves the atomiser. Besides its nozzle velocity, it is carried along by the air stream issuing from the gun. It is acted upon by gravity and convection currents. As its size decreases the relative importance of these various forces changes; gravity becomes less important and convection currents more. The movement of a droplet through still air under the influence of gravity is governed by well known physical laws which vary according to the size of the droplet concerned.

The largest of the particles (radius above 10^{-2}cm.) gain in velocity as they fall—Newton's Law:—

$$v = u + gt$$
$$\text{or } v^2 = u^2 + 2gs$$

where v = velocity, u = initial velocity, g = constant = 981 cms./sec., t=time and s=distance fallen in cms.

In practice the velocity attained is limited by the fact that droplets of liquids break up when they reach a speed at which the resistance of the air imposes a force greater than the surface tension.

Particles in the second group (radius 10^{-2} to 10^{-4} cms.) increase in velocity as they fall until a terminal velocity is attained when the resistance of the air just balances the weight of the falling particles—Stokes' Law.

$$v—2/9\ r^2 \frac{(P—p)g}{n}$$

where v = terminal velocity, r = radius of particle. n = viscosity coefficient of the gas, P and p = density of the particle and the medium through which it is falling, respectively.

It can be seen from the above equation that an increase in radius or gravity of the particle will increase the rate of fall as will a decrease in the viscosity coefficient of the gas. For droplets of water and oil (gravity 0·8) falling in air Stokes' Law gives the results set out in Table I. In this case p can be neglected and $n = 1{\cdot}81 \times 10^{-4}$ c.g.s., $x = 10^{-4}$ c.g.s., so that

$$\text{Terminal velocity} = 2/9 \frac{n^2\ P \times 981}{1{\cdot}81 \times 10^{-4}}$$
$$= 12 \times n^2 \times 10^5 \times P$$

TABLE I.

Diameter of Droplets		Rate of Fall			
		Water Droplets		Oil Droplets	
Microns	Cms.	Cms./sec.	Cms./min.	Cms./sec.	Cms./min.
1	10^{-4}	3×10^{-3}	0·180	$2{\cdot}4 \times 10^{-3}$	0·144
5	5×10^{-4}	75×10^{-3}	4·5	$60{\cdot}0 \times 10^{-3}$	3·6
10	10^{-3}	300×10^{-3}	18·0	$24{\cdot}0 \times 10^{-3}$	14·4
20	2×10^{-3}	1·2	72·0	0·96	57·6
50	5×10^{-3}	7·5	450·0	6·0	360·0
100	10^{-2}	30·0	1800·0	24·0	1440·0

The rate of fall of water and oil droplets (Sp. Gravity 0·8) in still air according to Stokes' Law.

The members of the third group of particles (radius below 10^{-4} cm.) approach in size the mean free path between the molecules of the gases composing air (10^{-5} cm.). This mean free path decreases with decrease in altitude. It comes about, therefore, that particles in this category decrease in velocity as they fall, an effect which is only apparent with appreciable changes in altitude—Stokes-Cunningham Law. In this third group of particles Brownian movement begins to be important.

In a mixed cloud consisting of particles in the three categories just discussed the largest particles fall past those of the other two groups and tend to impact with them. The same is true regarding those of the second and third groups. If the droplets evaporate rapidly, they may well decrease in size from the first group to third group as they fall. In still air all the droplets would gradually approach the substratum. In the presence of convection currents, which may be expected to occur in the spray chamber, the tendency would be for the largest particles to settle out but the smallest to be kept from appreciable settling and in fact to be carried upwards.

3. *The Properties of the spray-treated Atmosphere in relation to the Insect at Rest and in Flight.*

(*a*) *The Properties of the Mist Droplets.*

The spray-treated atmospheres, to which insects are exposed under the usual testing conditions, contain droplets of varying sizes, which, as a result of the preferential evaporation of the more volatile constituents, are different in composition from the original spray fluid. The droplets will also vary in composition among themselves since those injected first into the atmosphere will have evaporated most completely owing to the absence of contaminating solvent vapour in the air and because they have been formed for a longer period. Besides the above factors the smallest droplets will evaporate more rapidly than the largest. As a consequence of these differential rates of evaporation, the size of the droplet may come to bear but little relationship to the quantity of insecticides which it is carrying. The part played by the relatively inert ingredients in the spray in increasing the momentum or inertia of the toxic material contained in a droplet and so the tendency for impaction to take place should be noted.

(*b*) *The Change in Properties of the Spray Mist with Time.*

From what has already been said it will be realised that the number of detectable droplets in the sprayed atmosphere will decrease with time due to evaporation and precipitation, while the particle size distribution of the mist will also change as a result of the operation of the same processes. Since these alterations in the characteristics of the mist take place very rapidly (in a few seconds or minutes, depending upon the volatility of the spray fluid), the quantity impacting on insects exposed to it will not be the same unless all the individuals fly simultaneously. Any insects which are late in coming into flight will receive a smaller dose. This may be one of the reasons accounting for the different doses accumulated by individual flies in the Peet-Grady tests as reported by Murray (1940).

(*c*) *Uniform and ununiform spray Mist Dispersions.*

Two rather different types of spray dispersals to which insects may be exposed can be envisaged. The first may be described as " uniform "—in this type equal quantities of insecticide would be deposited on all stationary insects in comparable positions in a given time, or impacted on them when they flew for the same distance through the mist in a uniform manner. In the second " ununiform " type of mist neither of the above conditions would be fulfilled so that insects

behaving similarly at rest or in motion would still accumulate uneven doses of insecticide from the mist dispersion. "Uniform" mists would consist of very numerous small droplets, close together in relation to the size of the insect exposed or the volume which it traverses during flight, each carrying a small fraction of the lethal dose of toxicant. In "ununiform" mists there would be a relatively few large droplets present at considerable distances apart and occurring in unit volumes of chamber space large in comparison with the size of the insect or the volume swept during flight. This "ununiform" dispersal of large droplets might well occur against a "uniform" background of small droplets.

(*d*) *The Numbers of Droplets per Unit Volume of sprayed Atmosphere.*

The following considerations permit certain conclusions to be drawn regarding the uniformity or otherwise of typical insecticidal mist. Spray droplets produced by an average atomiser will vary in diameter from under one micron up to say fifty microns or even more in the case of the coarser types of mist produced by hand sprayers. Assuming the droplets to be all of uniform size or a mixture of two sizes the maximum numbers per c.c. of air space which could occur in the standard six foot cube Peet-Grady chamber dosed at the normal rate of twelve c.c. (*i.e.*, 55 c.c. per 1,000 cu. ft.) and in rooms treated at the rate of 10 c.c. per 1,000 cu. ft. (which is commonly recommended for practical application) are given in Table II.

TABLE II.

Dispersion	Number of Droplets per c.c. of air space	
	Peet-Grady Conditions 55 c.c./1000 cu. ft.	Practical Conditions 10 c.c./1000 cu. ft.
All as 10μ droplets	3770	680
50% Volume as 10μ droplets ... ... 50% Volume as 50μ droplets	1885 15	340 3
All as 50μ droplets	30	5

Theoretical number of droplets per c.c. of chamber space with three different dispersions.

(*e*) *The insecticidal Content of the spray Droplet in relation to the lethal Dose.*

It seems probable that such mist dispersions as the examples just given would be relatively uniform to flying insects, especially when the insecticidal charge in the droplets is small in comparison with the individual lethal dose. Unfortunately little precise information is available on this point, but a preliminary estimation of the median lethal dose of pyrethrum to *Aëdes aegypti* gives 1·0 mg. per Kgm. This figure may be compared with the following:—The median lethal dose of rotenone to the silkworm larva has been determined as 3·0 mg./Kgm. (Shepard and Campbell, 1942), while the surface median lethal dose of DDT to *Aëdes* is at most about 5-7 mg./Kgm. (David, unpublished). If 2 mgm. is taken as the weight of a single *Aëdes aegypti* female each would require about 0·002 gamma pyrethrins as the lethal dose. One 10μ diameter drop of a 0·1 per cent. solution of pyrethrins contains only 0·522 $\times$ 10^{-6} gamma. Therefore, in order to acquire a lethal dose from a 0·1 per cent. solution of pyrethrins applied as a mist, the insect would have

to accumulate about 3,825 originally 10 micron droplets or 30 droplets originally 50 microns in diameter. The specified numbers could occur in not less than about 1 c.c. of chamber space under Peet-Grady conditions assuming a uniform dispersal and in 5-6 c.c. under room test conditions (10 c.c./1,000 cu. ft.), and these volumes would have to be effectively swept by the mosquito in order to acquire a lethal dose. When the standard dose of 12 c.c. of a 0·1 per cent. solution of pyrethrins is applied in the Peet-Grady chamber (volume 216 cu. ft.), the quantity of pyrethrins per c.c. of chamber space assuming uniform dispersion would be not more than 0·00195 gamma while at 10 c.c. per 1,000 cu. ft. the maximum quantity present would amount to 0·000354 gamma. These quantities are not likely to be attained in practice.

The observations of Murray (1940) already referred to have shown, however, that the variation in individual doses accumulated by houseflies in the Peet-Grady test is as great as if any quantity of spray between 12 and 36 c.c. had been injected into the chamber. It must be concluded, therefore, that the spray dispersal is more ununiform than that just envisaged and that certain flies encounter by chance one or several uniformly dispersed particles or that alternatively different individual flies vary greatly in their activity so that the more active flies impact the greatest quantity of insecticide. Possibly both these factors operate simultaneously. It is well known that individual insects vary in their resistance to poisons but it can be seen that as long as the dose of insecticides accumulated by individuals varies it will not necessarily be the susceptible insect which succumbs or the innately resistant which survives.

(f) *The Insects exposed to the spray Mist—motionless Insects.*

The impaction of a spray droplet upon an insect may be brought about primarily by the movement of the droplet or of the insect and in certain circumstances the movements of both will contribute to the collision. When the movement of the droplet is primarily responsible, the insect will be struck at random on any part of its body, but it has been shown that with flying insects in a more or less stationary mist the vast majority of the particles are accumulated on the wings (David, 1945). In order to analyse further the relationship between the insect and the mist, the situation may be simplified by imagining a stationary mist of uniformly distributed particles all of which have about the same radius. If an insect is introduced into such a mist and remains motionless, it will only encounter a droplet with certainty if one occurs in each unit of chamber space equal to its own volume. At lower droplet frequencies the ratio of the insect volume to the volume containing a mist particle determines the chance of contact. The droplets are, however, almost always in motion, so that the stationary insect may be struck by a droplet falling under gravity, carried along by a convection current, or moving in the air stream from the gun. In the two latter cases impaction only takes place when the inertia of the particle is sufficiently great to prevent it being diverted in the air stream lines around the insect.

(g) *The Insects exposed to the spray Mist—flying Insects.*

If instead of remaining motionless the insect flies through the mist, it will encounter all those droplets that occur in the volume which it sweeps during flight, but it will not necessarily impact with them since many of the smaller particles will be diverted in the air stream lines around the insect. Whilst in flight the movements of the insect will usually be primarily responsible for the collision with the mist droplets although it is, of course, possible that the flying insect may be hit by a droplet leaving the gun, as when a hand-sprayer is directed towards houseflies in practical control. The movements of the insect in flight may be divided into two categories, the motion of the body through the air and

the vibration of the wings. The speed of flight of *Aëdes aegypti* in still air at 24-27°C. varies between 9 and 37 cm./sec. in case of different individuals and 17 cm./sec. may be taken as an average figure (Kennedy, 1939). The average speed of wing tip movement of various diptera is given as 550 to 640 cms./sec. (Magnan, 1934). This figure is said to be fairly constant for different species because insects with small wings beat them more rapidly. Taking average ratios of 17 cm./sec. for the rate of movement of the mosquito and 600 cms./sec. for the speed of the wing tip it may be seen that the wing tip moves some 35 times as fast as the mosquito. This value is probably too high since, on the assumption that the frequency of the wing beat in the mosquito is about 300 per sec. (Voss, 1914), the speed of 600 cms./sec. given for the wing tip implies that a displacement of the tip amounting to one centimetre would have to take place. A much lower value is obtained if the speed of movement of the wing tip is calculated from the displacement of the tip which was found to be about 0·25 cms. and the frequency of vibration which has been given as 300 per sec. for a mosquito (Voss, 1914). These values give 150 cms./sec. for the speed of the wing tip which is only some nine times as fast as the mosquito flies. In either case, however, in view of the fact that the wing tip moves more rapidly than the insect during flight, it is not surprising to find that very many more droplets impact upon the wings than on the rest of the body (David, 1945).

(*h*) *Transit Volumes.*

The volume of atmosphere swept by the insect during flight may be conveniently referred to as the transit volume which is obviously dependent upon the distance flown. Since the distance that individual insects in a given exposed batch fly will almost certainly vary, the quantity of insecticide accumulated by each will be different even when equal transit volumes contain the same number of droplets of equal size. In this connection it will be remembered that the impactibility of the insecticide is dependent upon the size of the droplet in which it is contained. A small concentrated droplet which has undergone evaporation will, therefore, be less likely to impact than a large droplet containing the same quantity of toxic principle.

In a hypothetical case all the transit volumes might be equal in respect to the volume swept in which instance an insecticidal mist produces a 100 per cent. kill if there is an impactable lethal dose of insecticide in every transit volume. If the droplets contain twice the necessary lethal dose, and they occur in 50 per cent. of the transit volumes, they would theoretically lead to a 50 per cent. kill, each insect having twice the necessary lethal dose. By halving each drop and so obtaining one per transit volume, chance would be eliminated and a 100 per cent. kill of insects flying through the mist would result. In this ideal case one droplet containing the minimum lethal dose occurs in each transit volume, and no more efficient distribution could be imagined. It can be seen that if in this last case 10 per cent. of the droplets were divided into very numerous smaller particles and re-dispersed in the mist, this would result in a 10 per cent. reduction in the kill in an ideal case.

The above statement may be viewed from the reverse approach. Consider a uniform mist that contains just below the toxic dose per transit volume. There is a 100 per cent. chance of picking up this just sub-lethal dose but no chance of picking up a lethal dose. It is obvious that by re-dispersing the mist and making it ununiform so that some transit volumes contained less than originally and others more a chance percentage kill of quite a high order could be produced. This redistribution could be affected by fusing some of the originally occurring droplets so that one of the fused droplets plus the remaining fine mist of one transit volume represented a lethal dose.

Experimental Results.

1. *Introduction.*

In considering the properties and behaviour of an atomised spray attention could be devoted to three main groups of factors:—

(*a*) Those that influence the degree of atomisation of the material leaving the spray gun nozzle, *e.g.*, design of spray gun, air pressure, air/liquid volume ratio, viscosity, and surface tension of the spray fluid.
(*b*) Those that influence the behaviour of the mist once it has been produced and which are an expression of the physical and chemical properties of the spray, *e.g.*, vapour pressure, size of the droplet and specific gravity.
(*c*) Those that also influence the behaviour of the mist once produced but are an expression of the properties of the environment through which the droplet passes, *e.g.*, temperature, humidity, and degree of saturation with any volatile constituents of the spray.

For the present purpose, however, these factors will not be considered separately but as they are summed up in the observed evaporation and precipitation of the cloud of spray droplets which leaves the atomiser. Reference to the literature on testing and use of insecticidal sprays shows that they are commonly applied at under about 60 c.c. per 1,000 cu. ft. The Peet Grady standard dosage represents 55 c.c. per 1,000 cu. ft. while the Army recommend the equivalent 10 c.c. per 1,000 cu. ft. for anti-mosquito sprays. Certain preliminary observations showed that the effective droplets were likely to be under fifty microns in diameter.

Starting with the above information calculations may be made concerning the number of droplets and the rate of precipitation and evaporation in clean air. The following table shows the number of droplets of the stated diameter which could be produced by the uniform atomisation of 1 c.c. of spray fluid, and the rate of precipitation according to Stokes' Law and of evaporation of these droplets assuming a gravity of 0·8 and an air temperature of 28°C.

TABLE III.

Diameter of Droplet Produced		Number Produced	Rate of Precipitation		Time of Evaporation (sec.)
Microns	Cms.		Cms./sec.	Cms./min.	
1	10^{-4}	$1{,}920{,}000 \times 10^6$	$2\cdot4 \times 10^{-3}$	0·144	—
5	5×10^{-4}	$15{,}330 \times 10^6$	60×10^{-3}	3·6	—
10	10^{-3}	$1{,}920 \times 10^6$	240×10^{-3}	14·4	0·3
20	2×10^{-3}	240×10^6	0·96	57·6	—
50	5×10^{-3}	$15\cdot35 \times 10^6$	6·0	360·0	—
100	10^{-2}	$1\cdot92 \times 10^6$	24·0	1440·0	30·

Showing the number of droplets produced by the atomisation of 1 c.c. of spray fluid, the rate of precipitation and the time of evaporation in the case of odourless kerosene.

From Table III it can be seen that a fifty micron droplet, in the absence of convection currents falls about a foot in five seconds so that on this account alone, few would be expected to remain in suspension in a Peet-Grady cabinet six feet in height thirty seconds after spraying. The time of evaporation represents evaporation into clean air. Under these circumstances evaporation of a droplet of odourless distillate is seen to occur very rapidly. As the droplet diminishes in size the rate of evaporation increases due to the comparatively steeper vapour

concentration gradient round the smaller droplet. When the surrounding atmosphere becomes partially saturated with the evaporating substance the rate of evaporation is considerably depressed. This effect is very noticeable within the region of dosages applied in spray testing and practical application (under 60 c.c. per 1,000 cu. ft.) although the saturation concentration of odourless kerosene in air at 28° C. is of the order of 50 gms. per cubic metre and ordinary kerosene 100-150 gms. per cubic metre (data supplied by the Asiatic Petroleum Co.). As will be shown later, a change in dose from 12·8 c.c./1,000 cu. ft. to 25·6 c.c./1,000 cu. ft. has a very marked influence on the rate of evaporation and so the particle size and persistence of the mist.

Most fly and mosquito sprays consist of solutions of toxic ingredients and adjuvants of various kinds in a volatile base such as kerosene. It is obvious that where the toxic ingredients are non-volatile the concentration of the insecticide in the droplets will increase enormously with evaporation and the whole droplet will undergo marked changes in composition. The droplet which reaches the insect may, in fact, be a highly concentrated solution or pasty suspension of the insecticidal ingredient in the non-volatile adjuvant.

2. *Experimental Methods.*

(*a*) *The spray Chamber.*

All the experiments described in this investigation were carried out in a zinc lined spray chamber measuring $3\frac{1}{2} \times 4 \times 4$ ft. (actual volume 54·5 cubic feet = 1,543 lit.). A full description of this equipment has already been given (David, 1946). Before the tests were carried out the chamber was brought to 28° C. and 70 per cent. relative humidity unless otherwise stated. The spray solution was introduced from an Aerograph M.P. type spray gun fitted with a No. 1 nozzle. This atomiser was usually operated at a pressure of 12·5 lbs. per sq. inch. The volume of air sample drawn for particle size distribution measurements, etc., was never more than 1/200th of the volume of the chamber.

(*b*) *The Sampling Apparatus.*

Four different procedures were employed in order to follow the behaviour of the spray mists in the chamber.

i. *A sintered glass Funnel.*

The total amount of insecticide (represented always by Sudan III dye) remaining in the air space without reference to particle size was measured by drawing a known volume of the treated atmosphere through a sintered glass funnel (pore size 15-40μ) and estimating the dye collected colorimetrically (Potter & Hocking, 1939).

ii. *A glass Slide.*

The total quantity deposited on the base of the cabinet was measured by collecting the material on a glass slide (usually 6×7 ins.) and washing the dye into a colorimetre tube and comparing with standards. During the first two minutes of the sampling period the slide was moved slowly backwards and forwards across the floor of the chamber.

iii. *Mist Sampler, type* 1 (Cascade Impactor).

The particle size distribution of the mist and the changes which take place under different conditions were followed by means of the Cascade Impactor. A full description of this instrument has recently been published by the designer (May, 1945) it divided particles of unit gravity into four groups as follows:—

Group 1	particles	between	200-10 microns
,, 2	,,	,,	20- 3 ,,
,, 3	,,	,,	7- 1 ,,
,, 4	,,	,,	3- 0·7 ,,

With the more dispersed clouds which this sampler was designed to investigate the individual particles could be measured but in the case of insecticidal mists the deposit in the apparatus was so heavy that this was no longer possible. The deposited droplets in each group were therefore taken up in one c.c. of odourless kerosene and the quantity present in each particle size range was estimated colorimetrically and expressed as a percentage of the total quantity of spray injected into the chamber which could have occurred in the volume sampled.

(iv) *Mist Sampler, type* 2 (Sliding Impactor).

The details of this piece of apparatus may be seen by reference to fig. 1. It was improvised from a block of wood measuring 18 × 3·5 × 3·5 cms. through which a hole 2·75 cms. in diameter had been bored from one end to within about 1 cm. of the opposite end. Through this end the hole was only 2 cms. in diameter and was closed by a rubber bung carrying a piece of thick walled capillary tubing 10 cms. long. The opposite end was also closed by a rubber bung carrying a piece of ordinary glass tubing to which the suction line was attached. Half way along the upper side a hole was cut, and through this the sampling nozzle was passed and sealed in position with jointing wax. The nozzle consisted of a piece of thin walled brass tube 2·3 cms. long, oval in section at the outer end (0·7 × 0·55 cms.), and hammered to a slit with parallel sides at the inner end. The slit measured 0·4 × 9·5 mms. and was placed at a distance of 2 mms. from the collecting surface. The air flow through this jet was examined and showed no

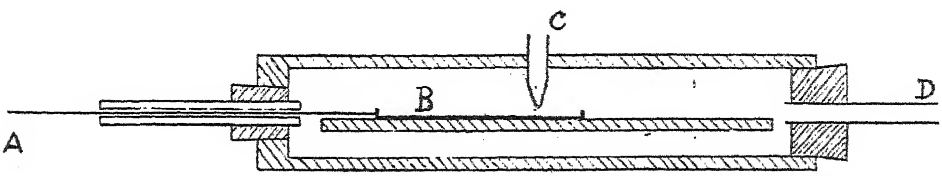

Fig. 1.—Diagram of sliding impactor. A, wire handle attached to slide holder B; C, nozzle through which sample of mist enters; D, suction line.

turbulence under the conditions at which it was to operate. A horizontal platform was arranged along the length of the bore through the wooden block so that it terminated within a short distance of each end and so permitted the insertion of the rubber bungs already referred to. A metal plate with slightly upturned ends just large enough to take a 3 × 1 inch microscope slide was placed on this platform and could be moved backwards and forwards under the nozzle by means of a piece of wire 25 cms. long which was soldered to one end and which passed through the capillary tubing, already described, to the outside. The bore of the capillary tube, which was just large enough to take the wire, was coated with vaseline in order to form an airtight gland.

When in use the apparatus was connected to a suction line and the air speed through the nozzle was adjusted to thirty miles per hour by means of a capillary resistance in the air line. The incoming mist droplets were collected either on a plain microscope slide or on a slide having a shallow trough 2 × 1 cm. and 50 microns deep formed by cementing on strips of cover slip. In both cases during sampling the slide was moved backwards and forwards across the nozzle so that the sample was obtained in the form of a band 3-4 cms. long. The plain slide was coated with a 2½ per cent. solution of Cumarone Resin, "Cumar P25°", in toluene which was pipetted over it and allowed to drain. Kerosene droplets striking this film produce small rings which can be seen clearly under oblique transmitted

light. (I am indebted to Mr. H. Liddell for developing this medium.) The technique was employed in estimating the number of droplets in a given volume of sprayed atmosphere. In order to estimate the size of the droplets they were collected in a liquid medium consisting of 50 per cent. volume of a 5 per cent. wt./vol. solution of gelatin in water and 50 per cent. " Teepol " wetting agent (Messrs. Technical Products Ltd.). The above mixture was shaken with a small quantity of odourless kerosene (to reduce the solubility of the spray droplets) and allowed to separate overnight. The clear solution was drawn off and a small quantity placed in the trough of the collecting slide already described. After the droplets had been collected, the trough was carefully covered by a piece of cover-slip moistened with the medium. In this medium the droplets of the odourless kerosene sprays formed spheres which could be easily measured. In the presence of pyrethrum the droplets no longer formed into spheres.

When the samples were being drawn, the apparatus was mounted just behind one of the windows in the front of the spray chamber previously described (David, 1946). For this purpose the window was replaced by a piece of plywood containing a small inset window and a hole through which the wire controlling the position of the slide protruded to the outside of the cabinet. The suction line to the sliding impactor passed through an adjacent window. During the course of sampling the slide was moved backwards and forwards across the sampling nozzle by means of the wire attached to the plate carrying the slide. The precise procedure and the volume of sample drawn was varied according to the expected number of particles per unit volume of the mist. The particle size distribution was obtained by counting systematically across random areas of the trough. A similar procedure was adopted in assessing numbers from the resin coated slides. Five cross sections of known width were taken, which, together with a knowledge of the total length of the trace, and the volume of the sample, gave the necessary data for calculating the number of particles per unit volume of sprayed atmosphere.

Before passing to a description of the experimental results it is perhaps necessary to point out that neither of the impactors collected mist particles below about one micron in diameter with 100 per cent. efficiency under the conditions at which they were operated. Indeed the characteristics of the sliding impactor are unknown, and it would probably not be safe to assume that the collection of droplets below about five microns diameter was 100 per cent. efficient. Although the latter apparatus was inefficient in sampling the smaller particles the results obtained by its use showed highly significant differences between clouds known to possess different insecticidal properties.

It follows from what has just been said that a low recovery from the air space with an impactor sampling device may mean either that the spray has settled out and therefore no longer exists in suspension or that the particles have become so fine by evaporation that they pass through the impactor. The sintered glass funnel on the other hand is believed to be nearly 100 per cent. efficient as a collector and certainly retains particles very much smaller than the stated pore size.

(*c*) *The Spray Solutions.*

No insecticidal sprays were utilised in this investigation since preliminary experiments indicated that the presence of insecticidal ingredients increased the difficulties, which were already considerable, in obtaining results. For example, the presence of pyrethrum extract in the spray caused the droplets to spread in the liquid droplet collecting medium and they no longer gave clear traces on the cumarone resin film. The latter difficulty may have arisen because the solubility of the resin in the odourless kerosene spray was depressed by the presence of resinous material from the pyrethrum extract in the droplets. The deposit from dyed solutions of 0·5 per cent. w/v DDT on the cumarone resin film were also

difficult to deal with, since, although the larger droplets gave clean rings, there were also present, after evaporation, a very large number of almost dry particles of DDT mixed with dye and a little residual solvent which were extremely difficult to see and count.

The solutions actually employed were:—

i. Odourless kerosene dyed with approximately 0·1 per cent. wt./vol. Sudan III taken to represent a solution of non-volatile insecticide of low total non-volatile content.

ii. Odourless kerosene containing 5·0 per cent. v/v high vacuum pump oil (H.V. Oil) dyed with Sudan III as before and taken to represent a non-volatile insecticide supplemented with a non-volatile adjuvant or other ingredients.

iii. Odourless kerosene dyed with Sudan III as before and containing 1·0 per cent. v/v H.V. Oil was also employed as an intermediate type of spray.

The characteristics of the various oils composing the sprays are set out in Appendix I.

3. *The Suspension, Deposition and general particle Size of the spray Mist as shown by the Sintered Funnel, the glass Plate on the Base of the Cabinet and the Cascade Impactor.*

(*a*) The effect of changes in the spraying pressure, and the age of the mist on the distribution of the insecticide in the spray cabinet and the effect of similar changes on particle size and persistence of the mist.

A spray solution consisting of 0·7 c.c. of odourless kerosene dyed with Sudan III was injected into the spray chamber under the conditions described at 7·5, 12·5 and 20·0 lbs. per sq. inch and samples were collected in the Cascade Impactor, the Sintered Funnel and on the plate on the base of the cabinet. The results obtained are set out in Tables IV and V.

TABLE IV.

Spraying Pressure lb. sq. inch	Sample from	Time of Sampling (min. after spraying)			
		½	2	4	10
7·5	Air	80	60	60	50
	Base	15	20	30	35
	Total	95	80	90	85
12·5	Air	80	75	65	60
	Base	10	10	15	20
	Total	90	85	80	80
20·0	Air	80	80	75	65
	Base	5	10	10	15
	Total	85	90	85	80

Sintered funnel and plate on the base of the cabinet. The figures in the body of the table show the percentage of the Sudan III representing non-volatile insecticide recovered from the air space, the base of the cabinet and the total accounted for.

TABLE V.

Spraying Pressure lb. sq. inch	Sample from Plate	Time of Sampling (min. after spraying) ½	2	4	10
7·5	1	10	5	0	0
	2	25	20	10	5
	3	10	15	20	15
	4	10	10	10	10
	Total	55	50	40	30
12·5	1	5	5	0	0
	2	25	15	5	5
	3	10	20	25	15
	4	10	10	15	15
	Total	50	50	45	35

Cascade Impactor. The figures in the body of the table show the percentage volumes of the spray injected which were recovered from the air space on each plate of the impactor. The particle size range collected on the four plates is given in the text.

Conclusions from Tables IV and V.

The following conclusions may be drawn from the experimental results given in Tables IV and V.

(i) An increase in the spraying pressure from 7·5 lbs. to 20 lbs. per square inch leads to slight increase in the percentage of spray remaining in the air and the duration of the suspension. There is a corresponding decrease in the percentage deposited on the base. No clear effect on the particle size distribution could be shown between 7·5 and 12·5 lbs. per square inch.

(ii) The percentage of spray remaining in suspension in the air decreases with time, Table IV, and the particle size becomes smaller, Table V. In connection with the latter it will be noted that the maximum recovery in the half-minute sample is on the second slide, while in the four-minute sample it is on the third slide.

(iii) The recovery in the impactor is less than that in the sintered funnel as would be expected from the fact that the impactor does not collect the smallest particles.

(iv) As would be expected from conclusion (ii) above, the insecticidal efficiency of the spray decreases with time. Thus it has been shown in a previous paper (David, 1946, Table VII) that when *Aëdes aegypti* were exposed at 0·5, 2, 4 and 10 minutes after spraying 0·1 per cent. pyrethrins in odourless kerosene, the following percentage kills were observed respectively: 83, 70, 66, 50. (Angles 65·5, 57·0, 54·0, 44·8$\pm$0·8°.)

(*b*) The effect of pre-treating the chamber with odourless kerosene so as to saturate the atmosphere partly and a similar experiment with white oil, P31, of low vapour pressure.

Tests were made with odourless kerosene and the white oil P31 for the sake of comparison. The chamber was first sprayed with an excess (10 c.c.) of the undyed oils and then ten minutes later with 0·7 c.c. of the dyed oils. The results obtained are shown in Table VI.

TABLE VI.

Sample from Plate	½ minute sample			
	Odourless. No pretreatment	Kerosene Pretreated	P. 31	
			No pretreatment	Pretreated
1	5	20	25	20
2	25	35	15	20
3	10	5	5	5
4	10	0	0	0
Total per cent. ...	50	60	45	45
Base per cent. ...	10	30	50	50
Total per cent. ...	60	90	90	90

Cascade impactor and glass plate on the base of the cabinet. The figures in the body of the table give the percentage volume of spray existing within the particle size range corresponding to each plate of the impactor and the amount deposited on the base.

Conclusions from Table VI.

(i) The figures for odourless kerosene show clearly that pre-treating the atmosphere with an excess of the undyed oil depresses the rate of evaporation of the dyed odourless kerosene subsequently injected.

(ii) As a result of the depression of the rate of evaporation of the odourless kerosene spray in the pre-treated atmosphere the droplet size distribution of the cloud of particles formed from it approaches more closely to that of the P31 atomised at the same pressure (the latter, however, takes much longer to pass through the gun). This observation serves to emphasise the important part played by evaporation as compared with actual degree of atomisation in determining the particle size distribution of the clouds.

(iii) The quantity of dyed spray deposited on the base from the odourless kerosene pre-treated atmosphere is also greater than that from the untreated atmosphere as would be expected if the particle size remained larger.

(iv) These effects are not apparent with the relatively non-volatile P31 oil.

(*c*) The influence of the volatility of the carrier on the persistence and distribution of the mist.

When petroleum ether, odourless kerosene and white oil, P31, are sprayed under identical conditions through the atomising gun, the clouds produced at the nozzle will have substantially different particle size distributions. Table VI presents evidence that this difference is not so great as might be expected from a direct comparison of the mists after half a minute has elapsed, or from a consideration of the comparative viscosities of the oils. This lesser difference is due to the fact that the three sprays take very different times to pass through the gun nozzle. P31 takes three times as long as odourless kerosene and there is, therefore, more energy available for its atomisation. The comparative behaviour of these three sprays then may be regarded very largely as an expression of their different volatility characteristics. Table VII shows the distribution between air space and the base of the cabinet and Table VIII shows the particle size distribution of the mists as given by the Cascade Impactor.

TABLE VII.

Spray	Sample from	Time of sampling (min. after spraying) ½	2	4	10
Petroleum ether	Air	80	80	80	70
	Base	0	0	2·5	5
	Total ...	80	80	82·5	75
Odourless kerosene	Air	80	75	65	60
	Base	10	10	15	20
	Total ...	90	85	80	80
White oil, P31	Air	50	40	30	20
	Base	50	50	60	70
	Total ...	100	90	90	90

Sintered funnel and plate on the base of the cabinet. The figures in the body of the table show the percentage distribution of the spray, as represented by the dye, between the air and the base of the cabinet and the total accounted for. Spray 0·7 c.c. injected at 12·5 lb. per sq. inch.

TABLE VIII.

Spray	Sample from plate	Time of sampling (min. after spraying) ½	2	4	10
Petroleum ether	1	0	0	0	0
	2	5	5	5	5
	3	15	15	15	10
	4	15	15	15	15
	Total	35	35	35	30
Odourless kerosene	1	5	5	0	0
	2	25	15	5	5
	3	10	20	25	15
	4	10	10	15	15
	Total	50	50	45	35
White oil, P31	1	25	10	1	0
	2	15	20	15	10
	3	5	5	5	5
	4	0	5	1	1
	Total	45	40	22	16

Cascade Impactor. The figures in the body of the table show the percentage volume of spray existing within the particle size range corresponding to each plate of the impactor and the total recovered in the instrument. Spray 0·7 c.c. injected at 12·5 lb. per sq. inch.

Conclusions from Tables VII and VIII.

(i) Table VII shows that when petroleum ether, odourless Kerosene and P31 are sprayed under the same conditions much more of the dissolved dye remains in suspension in the air from the petroleum ether solution than the P31 solution, due very largely to the much greater rate of evaporation of the former spray droplets so that they do not become deposited on the base.

(ii) The particle size distribution of the three mists is very different at the end of the first half minute. It changes but little with time, with the petroleum ether mist, since this has already largely evaporated, but the change with odourless kerosene and P 31 is much more marked (Table VIII).

(iii) The recovery in the impactor with the petroleum ether mist is low because the particles are so small that they escape impaction and in the case of the white oil spray it is low because the mist particles remained large enough to precipitate rapidly. This fact is confirmed by reference to Table VII.

(iv) From the foregoing conclusions it would be expected that a solution of pyrethrins in petroleum ether would be less effective as an insecticidal spray than a similar solution in odourless kerosene when the insects are exposed from the first half minute after spraying since the larger particles of the kerosene mist would impact more readily and the total quantity of insecticide remaining in suspension is essentially the same. After four minutes have elapsed, however, the difference in particle size distribution of the mists is much less and the two mists should then be about equally effective. These expectations are fully borne out in practice as shown in Tables IX and X. For these tests pyrethrin solutions containing very little inert resinous or other matter were employed since the presence of the resins would have served to increase the particle size. The test insect used was *Aëdes aegypti*.

TABLE IX.

Insecticide	Average per cent. kill in 24 hours	Average Angle $\pm$ 2·5
Pyrethrins in Petroleum ether	33	35
Pyrethrins in Odourless kerosene	70	57

Pyrethrins in Petroleum ether (BP 30/40°C.) and Odourless kerosene (BP 200/260°C). The insects were exposed to the spray free in the chamber for ten minutes commencing 0·5 min. after spraying 0·7 c.c. spray fluid at 12·5 lb. sq. inch. Temperature of cabinet 28°C., relative humidity 70%. Each average figure is based on four tests involving 100-200 insects.

TABLE X.

Insecticide	Average per cent. kill in 24 hours	Average Angle $\pm$ 1·6
Pyrethrins in Petroleum ether	44	41
Pyrethrins in Odourless kerosene	50	45

Pyrethrins in Petroleum ether and Odourless kerosene. The insects were exposed to the spray in cages for ten minutes commencing 4·0 min. after spraying under the conditions given for Table IX. Each average figure is based on four tests involving 100-200 insects.

(*d*) The influence of non-volatile material in the spray on the distribution, particle size and persistence of the spray mist.

Certain insecticidal sprays contain little non-volatile matter and others (*e.g.*, sprays containing activators such as Sesame oil) an appreciable quantity. These two types, as already explained, were represented by dyed odourless kerosene and the same solution to which 5 per cent. of non-volatile high vacuum pump oil had been added. These two solutions do not differ appreciably in viscosity but their volatility characteristics are very different on account of the presence of non-volatile constituents in the latter.

Tables XI and XII show the distribution of the two sprays between the air space and the base of the cabinet and the particle size distribution.

TABLE XI.

Spray	Sample from	Time of Sampling (min. after spraying) ½	2	4	10
Odourless kerosene	Air	80	75	65	60
	Base	10	10	15	20
	Total ...	90	85	80	80
Odourless kerosene and 5 °/₀ H.V. oil	Air	85	70	65	60
	Base	15	20	25	30
	Total ...	100	90	90	90

Sintered glass funnel and plate on the base of the chamber. The figures in the body of the table show the percentage distribution of the sprays, as represented by dye, between the air and the base of the chamber and the total accounted for. Spray 0·7 c.c. injected at 12·5 lb. per sq. inch.

TABLE XII.

Spray	Sample from Plate	Time of Sampling (min. after spraying) ½	2	4	10
Odourless kerosene	1	5	5	0	0
	2	25	15	5	5
	3	10	20	25	15
	4	10	10	15	15
	Total ...	50	50	45	35
Odourless kerosene and 5 °/₀ H.V. oil	1	10	5	0	0
	2	40	40	35	20
	3	15	15	15	15
	4	5	5	5	5
	Total ...	70	65	55	40

Cascade Impactor. The percentage volume of spray existing within the particle size range corresponding to each plate of the impactor and the total volume recovered are shown. Spray 0·7 c.c. injected at 12·5 lb. per sq. inch.

Conclusions from Tables XI and XII.

(i) The addition of 5 per cent. non-volatile ingredients to the odourless kerosene is without a marked influence on the distribution of the contained dye between the air and the base of the cabinet.

(ii) The presence of the non-volatile ingredient leads first to an increase in the percentage recovered in the impactor and later to an increased percentage of the spray existing in the larger particle size range.

(iii) As would be expected a spray containing the non-volatile high vacuum oil has a higher insecticidal efficiency to *Aëdes aegypti* under the prevailing conditions because it persists as large droplets which impact with the insects more readily. This effect has been discussed in an earlier paper (David, 1946, Table IIIa) where it is shown that the addition of 5 per cent. volume of high vacuum oil to a 0·05 per cent. w/v pyethrins solution increased the observed kill from 20 per cent. to 78 per cent. (Angles 27 and 62 $\pm$ 1·1° respectively). The insects were exposed for ten minutes commencing at the fourth minute after spraying. Other similar tests have shown angular increments from 35 to 62 $\pm$ 1·2° and 20 to 48 $\pm$ 1·1° (*Ibid.* Table IX). By microscopic examination of the sprayed insects, it can be shown that the enhanced kill is in fact due to the collection of more numerous droplets, and this can be further confirmed colorimetrically when dyed sprays are used. The other possible explanation that penetration of the insecticide is facilitated by the presence of the non-volatile oil is, therefore, excluded.

(*e*) The influence of the volume of spray injected into the cabinet on the persistence and particle size of the mist.

Experiments were made in which the volume of spray injected into the cabinet was increased from 0·7 c.c. (= to 12·8 c.c./1,000 cu. ft.) to 1·4 c.c. (= 25·6 c.c./1,000 cu. ft.) and then to 2·8 c.c. (=51·2 c.c./1,000 cu. ft.). The atmosphere in the cabinet was sampled by means of the Sintered Funnel and the Cascade Impactor with the following results.

TABLE XIII.

Dose applied c.c.	Sample from	Time of Sampling (min. after spraying)			
		½	2	4	10
0·7	Air	80	75	65	60
	Base	10	15	15	20
	Total...	90	90	80	80
1·4	Air	80	70	60	45
	Base	20	30	35	45
	Total...	100	100	95	90
2·8	Air	75	55	45	30
	Base	20	35	45	55
	Total...	95	90	90	85

Sintered funnel and plate on the base of the cabinet. The figures in the table show the percentage distribution of the sprays, as represented by dye, between the air and the base of the cabinet and the total accounted for. Spraying pressure 12·5 lb. per sq. inch.

TABLE XIV.

Dose applied c.c.	Sample from Plate	Time of Sampling (min. after spraying) ½	2	4	10
0·7	1	5	5	0	0
	2	25	15	5	5
	3	10	20	25	15
	4	10	10	15	15
	Total	50	50	45	35
1·4	1	15	5	0	0
	2	40	30	20	5
	3	10	10	15	15
	4	5	5	5	10
	Total	70	50	40	30
2·8	1	20	10	5	0
	2	35	35	25	10
	3	10	10	10	10
	4	5	5	5	5
	Total	70	60	45	25

Cascade Impactor. The percentage volumes of spray existing within the particle size range corresponding to each plate of the impactor and the total volume recovered are shown.

Conclusions from Tables XIII and XIV.

(i) An increase in the volume of spray injected into the chamber leads to an increase in the percentage deposited on the base.

(ii) As a result of more rapid deposition less remains in the air space.

(iii) These effects are due to a depression of the rate of evaporation of the droplets resulting from partial saturation of the atmosphere with kerosene vapour. The effect on particle size is clearly shown by the Cascade Impactor samples.

(iv) The results emphasise the importance of evaporation as compared with initial atomisation in determining the particle size of the mist at low volume dosages of insecticides in the air space.

(v) As long as the greater rate of precipitation of the spray does not dominate the situation the persistence of larger particles, as the volume applied is increased, would be expected to lead to an enhanced insecticidal efficiency. This is shown to be the case in Table XV, where *Aëdes aegypti* was the test insect.

TABLE XV.

Insecticide	Volume injected	Average % kill in 24 hours	Average angle ± 1·5
Pyrethrins 0·08% w/v in odourless kerosene ...	0·7 c.c.	42	40
Pyrethrins 0·04% w/v in odourless kerosene ...	1·4 c.c.	70	57

Showing the effect of increasing the volume of the carrier on the insecticidal efficiency of an odourless kerosene spray as a result of the particle size being larger due to depression of the evaporation of the spray mist droplets. The insects were exposed for 10 mins. commencing ½ min. after spraying. The average figures are based on six tests each involving about 100 insects.

4. *The particle size of the spray mist as shown by the sliding impactor.*

The Cascade Impactor was not designed to sample such concentrated mists as those occurring in the spray chamber and consequently the deposit collected in the shortest practicable sampling time was too dense to permit the measurement of individual particles. For this purpose the Sliding Impactor was employed. This latter sampling device has not been calibrated so that its efficiency in sampling the lower particle size range is unknown. However, all that is required for the present purpose are comparative figures and the apparatus shows up clearly the differences between mists of different composition and the effects of ageing. As explained previously the droplets were collected in a liquid gelatin/"Teepol" medium.

In the first experiment 0·7 c.c. of dyed odourless kerosene was injected into the usual 54·5 cu. ft. cabinet with the results and under the conditions shown in Table XVI.

It will be noted that after the lapse of four minutes all particles above 3·3 microns have disappeared due to evaporation and precipitation. Actually, as has been shown in Tables IV and VI, the change is mainly due to evaporation. This is confirmed by reference to Table III where it can be seen that non-volatile particles within the size range concerned persist in the air space and would not reach the base of the cabinet within four minutes.

TABLE XVI.

Exp. No.	No. of drops measured	Sample drawn min. after spraying	% Number of particles up to stated diameter (microns)					
			3·3	6·6	9·9	13·2	16·5	19·8
1	443	0·5	32·0	44·6	17·4	4·0	1·1	0·9
2	231	0·5	33·0	39·6	19·5	6·1	2·2	0·0
3	426	0·5	31·4	41·0	19·5	4·5	2·5	0·9
Approx. average...	367	0·5	32	41·5	19	5	2	0·5
4	70	4·0	100	...	...	...	...	...
5	50	4·0	100	...	...	...	...	...
7	50	4·0	100	...	...	...	...	...
Approx. average...	56	4·0	100	...	...	...	...	...

Sliding impactor. Odourless kerosene dyed with Sudan III sprayed at 12·8 c.c./1000 cu. ft. into a 54 cu. ft. chamber maintained at 28°C. and 70% relative humidity. The figures in the body of the table show the percentage number of particles up to the stated diameter occurring within each range.

When the above experiment is repeated with 1·4 c.c. (25·6 c.c./1,000 cu. ft.) of dyed odourless kerosene injected instead of 0·7 c.c. (12·8 c.c./1,000 cu. ft.) the evaporation of the mist is depressed and the particle size distribution at the end of four minutes is entirely different. The marked effect of increasing the volume sprayed into the chamber will be noted (Table XVII).

TABLE XVII.

Exp. No.	No. of drops measured	Sample drawn min. after spraying	% Number of particles up to stated diameter (Microns)					
			3·3	6·6	9·9	13·2	16·5	19·8
8	366	4·0	52·5	32·8	10·1	3·5	1·1	—
9	465	4·0	50·7	30·3	16·5	2·0	0·5	—
Approx. Average	416	4·0	51·5	31·5	13·5	2·5	1	—

Sliding Impactor. Odourless kerosene dyed with Sudan III sprayed at 25·6 c.c./1000 cu. ft. into a 54 cu. ft. chamber. Other conditions as Table XVI.

If the spray injected into the cabinet contains an appreciable quantity of non-volatile ingredients the effect on the particle size and persistence of the mist is very marked (*see* also Table XII). The results obtained with dyed odourless kerosene containing 5 per cent. volume in high vacuum oil, Table XVIII, should be compared with those obtained in the absence of this ingredient, Table XVI. In the presence of the non-volatile ingredient there is but little change in the particle size distribution of the mist in the course of four minutes except in the higher particle sizes.

TABLE XVIII.

Exp. No.	No. of drops measured	Sample drawn min. after spraying	% Number of particles up to stated diameter (Microns)					
			3·3	6·6	9·9	13·2	16·5	19·8
10	644	0·5	56·5	34·5	7·2	1·3	0·5	—
11	626	0·5	69·0	22·6	6·4	1·5	0·5	—
12	744	0·5	70·6	23·6	4·2	1·5	0·0	—
Approx. Average	671	0·5	65·5	27·0	5·5	1·5	0·5	—
13	711	4·0	63·5	29·6	6·5	0·5	—	—
14	549	4·0	59·0	34·3	6·4	1·0	—	—
15	639	4·0	71·0	24·5	3·5	1·0	—	—
Approx. Average	632	4·0	64·5	29·5	5·5	0·5	—	—

Sliding Impactor. Odourless kerosene containing 5% non-volatile oil dyed with Sudan III. Conditions, etc., as Table XVI.

In concluding this section it is perhaps desirable to emphasise that the particle size distributions recorded are intended primarily for comparative purposes. Due caution should be exercised in drawing conclusions concerning the actual particle size distributions of the mists concerned since those recorded will be deficient in the smaller particle size ranges.

5. *The number of particles of spray mist per litre of chamber as measured by the Sliding Impactor.*

In order to visualise more clearly the nature of the sprayed atmosphere to which the insects are exposed in the spray chamber it is necessary to know the number of particles occurring in a unit volume. Obviously the numbers recorded by means of the Sliding Impactor will be too low since the smallest droplets will have evaporated to sub-microscopic size and would not be detected even if they were impacted. In fact, of course, these smallest particles and many others in the region of one micron in diameter will escape collection. With these reservations the following figures may be given for the numbers of droplets per litre of chamber space at a dosage equivalent to 12·8 c.c./1,000 cu. ft.

From Table XIX it is clear that the number of particles of impactible size declines rapidly over ten minutes, and that a spray containing an appreciable percentage of non-volatile ingredients yields a much larger number of particles within the impactible size range. It may be calculated that with the dosage applied in the chamber for these tests, which is equivalent to 12·8 c.c./1,000 cu. ft., the volume of spray applied would yield 7,000,000 uniform particles 5μ in diameter at the gun per litre of chamber space or 109,000 particles 20μ in diameter.

TABLE XIX.

Spray	Minutes after Spraying commenced			
	0·5	2	4	10
Dyed odourless kerosene	43,500 43,250	11,400 14,100	2,500 2,000	— —
Dyed odourless kerosene + 5% H.V. oil	160,500 176,500	124,000 114,000	92,300 102,000	70,500 63,000
Dyed odourless kerosene + 1% H.V. oil	84,500 93,500	67,500 68,300	46,600 42,300	22,900 17,900

Sliding Impactor. The figures in the body of the table show duplicate counts of the number of particles of all sizes collected in the impactor per litre of chamber space at a dosage of 12·8 c.c./1000 cu. ft., spraying pressure 12·5 lbs. sq. in., temperate 28° C., Relative Humidity 70%.

Summary and General Conclusions.

An attempt has been made to assemble the important factors concerned with the atomisation of a kerosene spray and to consider the behaviour of the spray alone, and in its relation with an insect flying through it.

The degree of atomisation attained by the spray gun is dependent upon nozzle design, the spraying pressure, the relative rate of liquid and air flow through the nozzle and such physical properties of the spray fluid as viscosity and surface tension.

All atomisers produce droplets of a variety of sizes which leave the gun with a considerable velocity and are carried along by the air current. At this stage they are at their maximum size and possess their maximum velocity so that the chance of impacting with an insect is great. Later on when the droplets have lost much of their velocity and volume (if they contained a non-volatile insecticide they will have become much more concentrated), they are much less likely to impact. It can thus be seen that a non-toxic carrier can increase apparent toxicity of a spray mist by assisting in the production of the momentum necessary for impaction (David and Bracey, 1944). On the other hand a reduction in the size of the droplet decreases the rate of loss from the air space by precipitation. In connection with evaporation the enormous change in concentration which occurs should be borne in mind. Within a few minutes the smallest droplets will have entirely evaporated, leaving only the non-volatile solute and before this stage is reached the droplet will have become super-saturated. Finally this non-volatile solute will exist as minute nuclei which, when they result from a fairly typical insecticidal formula containing up to say 5 per cent. non-volatile material, may be so small as to settle only very slowly.

Regarding the response of the insect to the spray mist, it may be said that this depends upon the resistance of the insect and the dose of insecticide picked up. Since the spray mist takes some time to distribute evenly and since it is more easily picked up during or immediately after spraying and by insects in flight, it can be seen that the dose received by individual insects will vary a good deal unless the insects behave identically so that under these conditions there is little correlation between the comparative effect recorded on individuals and their relative innate resistance.

To the above remarks arising out of the theoretical discussion which formed the first part of this paper must be added the following conclusions from the experimental work.

1. The behaviour of a kerosene mist (with and without added non-volatile ingredients) in a spray chamber of 54·5 cu. ft. capacity has been investigated using a sintered glass filter funnel to collect the total mist in the air space, a glass plate on the base to collect the deposited spray, the "Cascade Impactor" to investigate the general characteristics of spray cloud and a "Sliding Impactor" to measure the actual particle size distribution and to count the number of particles per unit volume. The aim being to obtain a reasonably comprehensive picture of a unit of the atmosphere to which the flying insect is exposed.

2. The particle size of the mist while initially determined by the characteristics of the atomiser and the properties of the spray fluid such as viscosity and surface tension is, once the particle has left the gun, largely determined by its ability to evaporate as expressed chiefly by its size, vapour pressure, and the quantity of vapour already present in the surrounding atmosphere. The rate of evaporation of the droplets is greatly depressed even when the atmosphere is very far from being saturated. If the spray contains materials of low vapour pressure the percentage of these present determines the ultimate particle size.

3. The effect of changing the spraying pressure on the particle size of the mist is largely masked by precipitation and evaporation (Tables IV and VI).

4. The difference in particle size in the mist obtained with odourless kerosene and white oil, P 31, when sprayed through the same gun at the same pressure, is to a large extent an expression of the greater rate of evaporation of the former (Table VI).

5. The more quickly the carrier evaporates the smaller the particle recovered and the greater the quantity of any non-volatile material present in the original spray which remains in suspension in the air space (Tables VII and VIII).

6. When non-volatile material is present in the spray this, by failure to evaporate, determines the ultimate particle size of the mist (Table XII, and Table XVI compared with Table XVIII).

7. When the volume of a volatile spray injected into the chamber is increased evaporation of the droplets is depressed so that they persist longer at a greater size level and so deposit more easily and are more readily impacted (Tables XIII and XIV, and Table XVI compared with Table XVII).

8. The number of particles per unit volume of air space decreases with time and a much greater number remains at a countable size when an appreciable quantity of non-volatile material is incorporated in the spray (Table XIX).

9. Wherever the attempt has been made, it has been possible to show that a decrease in the quantity of spray mist in suspension in the atmosphere and a decrease in particle size of the mist as measured by the sampling devices employed are attended, as would be expected, by corresponding reductions in the insecticidal efficiency of the mist as measured on *Aëdes aegypti*.

10. In assessing the insecticidal efficiency of a mist it is not sufficient to know the quantity of insecticide in suspension in the atmosphere, the particle size distribution must also be known.

11. It should be emphasised that the biological tests were all carried out on *Aëdes aegypti* and that the results may not be applicable without modifications to other insects.

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APPENDIX I.

Properties of the Spray Oils.

Property	Petroleum Ether	Odourless Kerosene	White Oil P 31	High Vacuum Pump Oil
Specific Gravity 20/4° C.	0·693	0·796	0·861	0·885 (at 15/4° C.)
Kinematic Viscosity at 20° C. Centistokes	0·516	2·569	31·23	185·2
Distillation Range (A.S.T.M. °C.)				
Initial Boiling Point	62	198	292	340 (approx.)
10% Vol. Recovered	67	209	318	—
50% Vol. ,, ...	75	227	348	—
90% Vol. ,, ...	90	254	382	—
Final Boiling Point	107	267	387	—
Vapour Pressure at 30° C. mm./Hg. ...	190	7	1	Negligible

The above table gives the properties of the spray oils as used in the course of the investigations described. The figures in the first three columns were kindly supplied by Messrs. Shell Marketing Co., Ltd., and those in the final column by Messrs. W. Edwards and Co., Ltd.

COMBINED SPRAYING TRIALS AGAINST THE SAN JOSÉ SCALE AND PEACH LEAF-CURL IN KASHMIR.

By A. P. Kapūr, M.Sc.

Introduction.

Kashmir valley is the largest deciduous fruit-growing tract in India, and, owing to the increased demand for fruit, many orchards, both large and small, have recently been laid out with technical assistance from the Department of Agriculture. Apple is the first choice of the fruit-growers, but as the trees begin bearing later than many stone-fruits, it is a common practice to plant peaches and nectarines between the rows of the young apple trees; this produces early returns without disturbing and exhausting the soil by ploughing and growing annual crops. With the rapid development of road transport, it is hoped that peaches will find a market outside the valley. The peaches of Kashmir are not so well known as are its apples and pears but with better attention to the trees an increase in production and an improvement in quality should be possible.

The full-grown peach trees in the valley suffer from a number of pests and diseases, the two most important of which are the well-known San José scale (*Quadraspidiotus perniciosus*, Comstock) and the peach leaf-curl caused by the parasitic fungus, *Taphrina deformans*. Despite the fact that both occur throughout the valley, progressive fruit-growers who have taken adequate measures against them are able to secure high yield and quality. The intensity of the scale infestation is sometimes so severe that a young tree left unsprayed for two consecutive years dies in the following spring. The effect of the parasitic fungus is also severe; in extreme cases as many as 70 per cent. of the leaves curl and drop prematurely towards the end of the season and the twigs begin to dry off. The scale is often controlled by applying a winter spray of diesel-oil emulsified with soap, but this spray has little effect on the fungus which increases rapidly. The expense and difficulty of spraying the same tree twice during the limited period when satisfactory spraying is possible does not find favour with the orchardist. As the author was engaged in working on the control of the San José scale—under the auspices of the Imperial Council of Agricultural Research, New Delhi—the opportunity was taken to make experiments with a combined spray.

Brief History of the Combined Spray of Bordeaux Mixture and Oil Emulsion.

Some twenty years ago, in the United States, combined control of the San José scale and peach leaf-curl was being accomplished by the use of lime-sulphur, which was then recognised as a standard remedy for scale insects and fungi. Following the widespread application of oil emulsion, some time after the first trial made by Ackerman (1923) in 1921-22, against the San José scale, a need was felt for a combined spray which included oil emulsion and would also act as a fungicide. The oil emulsion gave a cheaper and better control of the scale than lime-sulphur and so was considered an indispensable ingredient, while Bordeaux mixture was chosen for its fungicidal properties. A combination of Bordeaux mixture and kerosene was suggested by Slingerland as long ago as 1893; some years later a Bordeaux mixture-lubricating oil emulsion was tried out by Winston and his co-workers (1919, 1920, 1923) and also by Macrum (1919), who added glue, casein or a similar agent to stabilise the combination. The two ingredients were said to act as efficiently in combination as they would do separately and most of the published evidence was favourable. Reports (1926) were, however, received of loss of efficiency of the oil owing chiefly to the appearance of scum on the surface

of the spray mixture. Marlatt (1928) and Porter and Sazama (1930) found that the reduction in efficiency was unimportant if the concentration of the oil was above 1·5 or 2 per cent. On the basis of the work of the British chemist Pickering (1907), Burroughs and Grube (1923) prepared on a large scale oil emulsions in which Bordeaux mixture was used as emulsifier in place of soap. No heat was employed, the emulsification being accomplished by pumping the ingredients together. The cold-mixed emulsions remained stable on dilution with water and could be used even with hard water while the ingredients retained their respective properties. Pickering made an emulsion of the same specific gravity as that of water so that when mixed with water it would neither sink nor rise. Since varying quantities of copper sulphate and lime could be incorporated in the making of the emulsion, several formulae were given. Burroughs and Grube indicated that to emulsify one or two gallons of oil in one gallon of water the quantities of lime and copper sulphate could be varied from $\frac{1}{4}$ to $\frac{1}{2}$ lb. each. They also suggested the possibility of adding larger amounts of Bordeaux mixture to the emulsion in order to prevent its rising to the top; later workers gave different formulae, usually with larger quantities of lime and copper sulphate.

Preliminary Trials.

It was necessary to investigate the preparation of an emulsion in which diesel-oil was to be substituted for the engine and lubricating oils used in other countries, but before any serious experiment could be laid out preliminary spraying trials were conducted in the field during 1942-43. It was found that diesel-oil supplied by the Burmah Shell Oil Company under the brand "Attock, light-A"* gave a satisfactory emulsion provided fresh Bordeaux mixture was used. One pound each of copper sulphate and lime were found sufficient to emulsify 2 gallons of oil and 1 gallon of water to give 3 gallons of stock emulsion which, on dilution with 10 parts of water contained nearly 6 per cent. of oil and 1:1:33 proportion of Bordeaux mixture. For making boiled emulsion with soap, 1 lb. of soft soap was used for similar quantities of oil and water. While the oil percentage in the Bordeaux-emulsified spray proved satisfactory against the scale, the proportion of Bordeaux mixture was found insufficient against leaf-curl. The percentage of curled leaves varied from 16 to 25·2 after spraying with the above emulsion. The amount of copper sulphate and lime was therefore increased to the proportion of 4:4:50, as given by Chandler, Flint & Huber (1926), and it was hoped that this proportion would enable comparison with the other Bordeaux (5:5:50) treatments, in the experimental spraying.

Stock emulsion prepared with soap did not mix well with Bordeaux mixture and rose to the top in spite of frequent agitation, with the result that in the preliminary trials the percentage of dead scales was very different in the various samples. In the subsequent experiments, the emulsion was prevented as far as possible from rising to the top by constant agitation, but such action is seldom possible in large field-scale spraying conducted with bucket pumps. When the same tree was to be sprayed with Bordeaux mixture and oil emulsion separately at an interval of a few days, it was necessary to spray Bordeaux mixture first, otherwise owing to the oily surface it would not stick on the bark. Good weather was necessary for effective results, and consequently late autumn or early spring provided the most suitable conditions.

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*Specifications :—

Closed flash point (P.M.) min. 175°F.; setting point (I.P.T.) max. 30°F.; viscosity (Redwood I) max. 45" at 100°F.; ash max. 0·01%; water max. 0·25%; carbon residue (Conradson) max. 0·2%; specific gravity at 60°F. about ·87 to ·88; sulphur about 0·3%; hard Asphalt nil.

Experimental Spraying and Results.

A combined spraying experiment was conducted at Khudwani, Kashmir, during the early spring of 1944 on fifteen-year-old peach trees in a mixed plantation with alternate rows of apple trees. Three rows of 12 trees each were selected and sub-divided to give six blocks of six trees each. A tree was treated as a unit plot and the treatments were replicated six times and applied in a randomised manner. Counts of living and dead scales were made after four weeks and of healthy and curled leaves after six. The percentage of the oil was uniform in the treatments while the proportion of Bordeaux mixture was 5:5:50 except in one treatment where it was used as emulsifier in 4:4:50 proportion, as mentioned above.

Results of a combined spraying experiment against San José Scale and Peach Leaf-curl.

No.	Treatments	San José Scale			Peach Leaf-curl	
		No. of scales examined	Per cent. dead	Per cent. controlled	No. of leaves examined	Per cent. leaves curled
1	Boiled soap diesel-oil emulsion	771	100·0	100·0	600	12·1
2	Bordeaux mixture (5:5:50) followed on 5th day by treatment No. 1	876	98·6	88·9	600	5·1
3	Stock solution of treatment No. 1 diluted in Bordeaux mixture (5:5:50)	695	95·8	73·7	600	6·1
4	Bordeaux mixture (4:4:50) emulsified diesel oil	663	100·0	100·0	600	5·0
5	Bordeaux mixture (5:5:50) alone	746	84·5	16·6	600	4·6
6	Control	864	81·2	—	600	32·0

It will be observed that the best results against the scale were obtained with emulsions in which soap or Bordeaux mixture was used as emulsifier. Against the leaf-curl, Bordeaux was almost as effective when used with or before the oil emulsion as when used alone. Cold-mixed Bordeaux emulsion was superior to all other treatments as a combined spray against the scale as well as leaf-curl.

A reduction in the insecticidal efficiency of boiled soap emulsion was observed in treatments where it was mixed with Bordeaux or followed an application of the latter after five days. Porter and Sazama, who observed a similar reduction, believed that, like lime or kaolin and other dusts, the particles of Bordeaux mixture absorbed a certain amount of oil, the insecticidal value of which was consequently lost. From the treatment in which oil emulsion followed Bordeaux mixture it appears that the particles of the latter were capable of absorbing the oil on the bark after five days or perhaps even more. If this is the case, a similar absorption must take place in the cold-mixed Bordeaux emulsion which, however, does not show any apparent loss of its insecticidal efficiency. Although the amount of Bordeaux incorporated in it was less by $\frac{1}{5}$th than the amount in other treatments and may have absorbed proportionately less amount of oil, this difference alone could not reasonably be considered responsible for the difference in the results. Cold-mixture Bordeaux emulsion is essentially a quick-breaking type, which, as shown by recent researches of de Ong, Knight and Chamberlin (1927), English (1928) and Farrar (1936), has a definite advantage over the more stable soap emulsions. Flint and Bigger (1926) while working on the leaf-roller, *Archips argyrospila*, Wlk.,

showed that Bordeaux emulsions killed the eggs at lower oil concentration than the more stable emulsions. The advantage of quick-breaking emulsions lies in the fact that oil separates out as it strikes the bark, whereas in the stable emulsion a certain amount of oil which is held fast by the film of soap runs off the tree as waste. When soap emulsion is used in combination with Bordeaux, it suffers from the double disadvantage of being a stable emulsion and of losing oil by absorption by Bordeaux particles. In the cold-mixed Bordeaux emulsion although the latter disadvantage may apply, it is apparently offset by the quick breaking properties of the spray. Moreover Bordeaux mixture is a cheaper emulsifier than soap, not only because of the lower cost of copper sulphate and lime but also because the cost of fuel required for preparing soap emulsion is eliminated.

A properly made emulsion has no deleterious effects on the trees, and as the spraying of private orchards is carried out by trained operators of the Agricultural Department the element of risk arising from the use of incorrectly prepared emulsion is reduced to a minimum.

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EFFECTS OF BUSH CLEARANCE ON FLIGHTING OF WEST AFRICAN ANOPHELINES.

By Major C. R. Ribbands, R.A.M.C.

Introduction.

Early in 1942 extensive and expensive attempts to reduce the Anopheline infestation of military camps by bush clearing were in progress in the Gold Coast.

Evans (1938), in the standard reference book on West African Anophelines, said: " It is often stated that the presence of trees close to houses conduces to infestation by mosquitos. That this is probably borne out by facts is suggested by Gibbins's (1933) comparison of two similar huts situated at practically equal distance from breeding-places, and both inhabited by two natives, but differing in that one was dirty and surrounded by a dense growth of trees and elephant grass, while the other was clean and in the middle of a cultivated plot. The number of *A. gambiae* and *A. funestus* were twelve times as great in the former as in the latter ".

On the other hand, De Meillon (1937) reported that *Anopheles gambiae* and *A. funestus* frequently did not fly close to the ground, and so were not hindered even by dense bush 20-30 feet in height. A similar opinion was held by a committee of the League of Nations Malaria Commission, who reported (Hackett and others, 1938) that " We know of no instance where a small radius of clearing about houses or inhabited centres has done any good, but many instances where it has done great harm. Nevertheless the cutting of underbrush and trees round dwellings is an obligatory anti-malaria measure in many tropical settlements. No serious attempt seems to have been made to evaluate the results . . ."

The following experiments were designed to provide more information concerning this problem, and were part of a series of experiments made to determine the requisites of correct camp-siting, the general conclusions concerning which have now been summarised elsewhere (Ribbands, 1944 *a*).

The Effect of Bush Clearance on Anopheline Behaviour.

Methods.

The principal experiment was conducted at Krabonekrom, a village 2 miles from Sekondi, Gold Coast, between January and March, 1942. Krabonekrom was an aggregation of mud huts, which harboured large numbers of *A. funestus* and a few *A. gambiae*. These mosquitos bred in a large permanent swamp, the nearest edge of which was 880 yards from the village, in an easterly direction. Krabonekrom was only 500 yards from a military hospital, and for this reason the entire population was evicted and the mud huts were pulled down on 18th January, 1942. Three huts were left intact in the village: two of these (X, Y) were used for experimental purposes, and the third (Z) was occupied, for supervision purposes, by the experimenter.

The purpose of the experiment was to maintain a constant human population in huts X and Y, and to compare the Anopheline population attracted to these huts before and after the clearance of bush from the surrounding area.

In view of the very large short-term fluctuations in Anopheline numbers (Ribbands, 1944 *b*), counts of the number of Anophelines present before and after bush-clearing were by themselves valueless, and therefore three control catches were made in huts in surrounding areas. The number of Anophelines attracted to the experimental huts were considered as a proportion of the number attracted to these control huts, the latter being used as an index to the size of the local Anopheline population.

The mosquitos were invariably collected after killing them by spraying the huts with insecticide, which was a very satisfactory method of sampling (Ribbands, 1946). Catches were made between 7 a.m. and 9 a.m. except in Hut X, where they were at intervals during the night as well. Details of the catches and catching stations are as follows:

The experimental Catch.

Huts X and Y were both mud huts with iron roofs. Hut X contained 4 rooms, and hut Y contained 3 rooms. Each room was open at the eaves and had a small window and door. Seven natives slept regularly in these huts in which experiments described elsewhere (Ribbands, 1946) were being conducted simultaneously. In connection with both series of experiments, three of these natives slept in one such room of hut Y and another in the other end room of this hut; the other three natives slept together in a room in hut X, and these natives were disturbed, and the mosquitos attracted to them were caught, at intervals during each night. For the experiments now described, it is legitimate to group together, for each night, the entire catch from all seven of these natives. This catch will be referred to as the Experimental Catch.

The inner Control Catch.

Hut P was specially built for this experiment. It was a single mud room, roofed with iron, with a door and a window and open at the eaves.

The same three natives slept in it nightly throughout the experiment, and provided the Inner Control Catch. Hut P was situated 58 yards outside the area cleared of bush, and 190 yards from huts X and Y, in the direction of the breeding area.

The outer Control Catch.

The experimental area was a long distance from the nearest native civilian dwellings, and the nearest other inhabitants were white troops in Officers' and N.C.O.s' lines at least 500 yards away. These billets were not useful as catching stations, and the nearest suitable catching stations were (*a*) at R, a mud block pan-roofed hut 880 yards away in the vicinity of the Sisters' Quarters, in which slept a native servant, and (*b*) at S, a similar hut 650 yards away in the vicinity of the Hospital, in which slept three native orderlies. The average of both these catches provided the Outer Control Catch, which was considered an index to the size of the local mosquito population. It is regretted that additional catching stations were not available in this area.

Type of Bush ; Area and Method of Clearance.

The village was situated on one side of a gently sloping valley, and the hospital was on a small hill on the other side. All the vegetation within 200 yards of the hospital quarters had already been cut down, ostensibly as an anti-malaria precaution, and it was kept less than 1 ft. high throughout the experiment. The vegetation in the vicinity of the village was formed of mixed secondary bush, varying in height between 4 ft. and 15 ft.—the height being mainly dependent upon the date when cropping had last occurred.

In this bush there were two cassava plantations. One of these cassava patches was mature, and arrangements were made to harvest this patch at the time of bush clearance; the other patch consisted of cassava only 2-3 ft. high, and this patch was clean-weeded at the time of bush clearance. The latter patch is shown on the plan given in fig. 1.

The preliminary experiments occupied three weeks between 27th January and 16th February, and throughout this period daily catches were made in all the experimental and control huts. On 18th February Major K. Thompson, R.A.M.C., supplied a gang of 100 natives who were expert bush clearers, and these men cleared the area within the five days ending 23rd February. The men were equipped with machettes, and clearance was very thorough, everything being cut off very close to the ground level. The cut bush was left to dry as it fell.

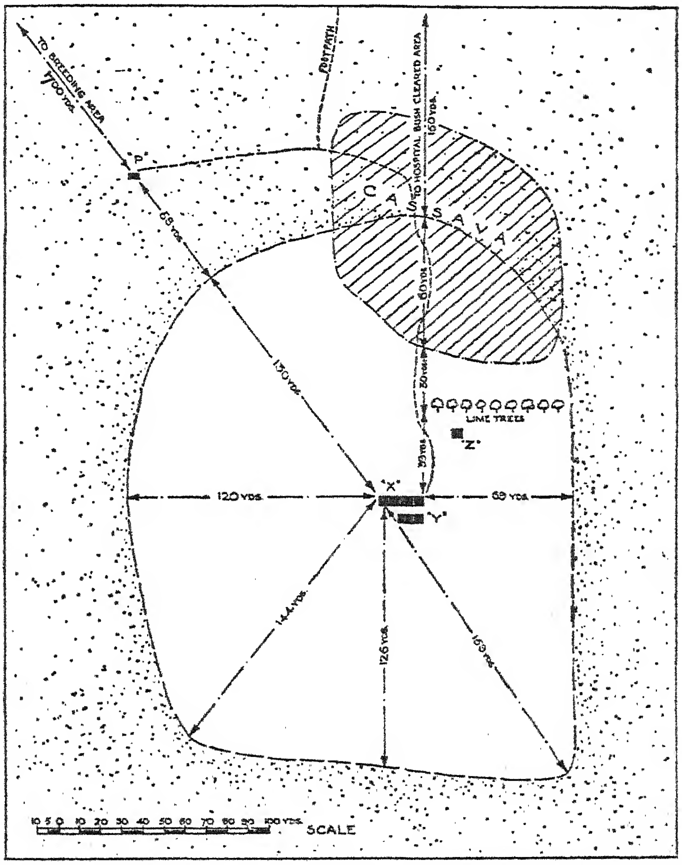

FIG. 1.—Plan of experimental area at Krabonekrom. The cleared area has been left unstippled.

The average distance cleared was 140 yards from the experimental huts, with a minimum distance of 130 yards in the direction of the breeding area. Fig. 1 shows the extent of the cleared area.

On 24th February the cut bush, now dry, was burnt, and the whole bush-cleared area, except the patch of clean-weeded cassava, was now covered with ash and almost bare of vegetation. The bush had been so thick that the ground flora had been very sparse, and very little even of this remained. The daily mosquito catches continued for a further three weeks until 16th March.

Comparison of the Mosquito Catches before and after Bush Clearance.

The mosquito catches before, during and after the bush clearance are set out in Table I.

The total number of mosquitos caught are included in the results given in Table I only in order to demonstrate the size of the catches upon which the results are based. The effect of the bush clearance cannot be judged in terms of the absolute number of mosquitos which entered the area before and after the clearing, but only in terms of the proportion of the local mosquito population which did so. Therefore in all cases the catches have been expressed as percentages of the catches in the Control Huts at the same time. These results are shown diagrammatically in fig. 2.

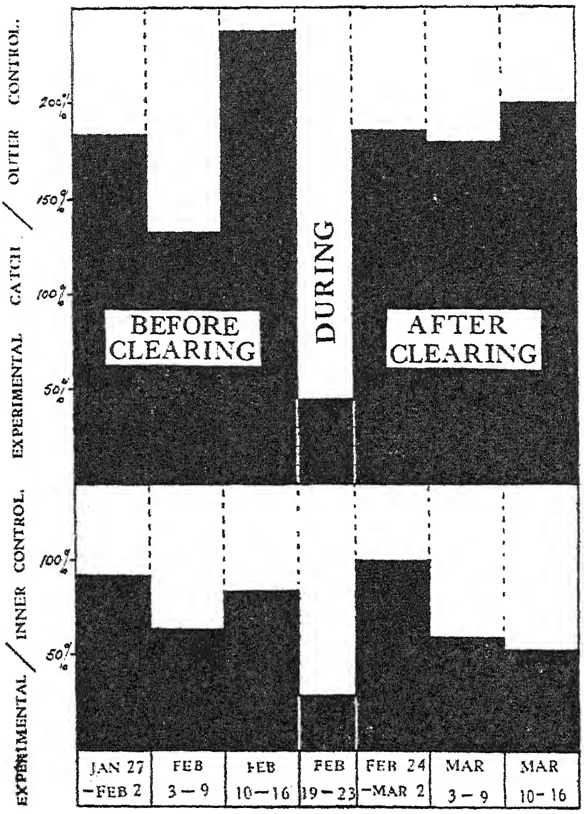

FIG. 2.—Proportions of ♀ *A. funestus* in cleared area before, during and after bush clearance.

It is best to defer consideration of the catches during the bush clearing period, and to compare first the catches before and after the clearance.

The experimental catch of ♀ *A. funestus* 22 days before bush clearance averaged 167 per cent. of the outer control catch and rose to 184 per cent. in the 21 days after bush clearance. In the same periods, and relative to the inner control catch, the values of the experimental catch were 77 per cent. and 71 per cent. respectively. Therefore there was little difference between the proportions of ♀ *A. funestus* which entered the experimental area before and after bush clearance.

The experimental catch of ♀ *A. gambiae* before clearance averaged 36 per cent. of the outer control catch, and declined to 26 per cent. after the clearance. This decrease was accompanied by a decline from 100 per cent. to 81 per cent. in the size of the inner control catch relative to the outer control catch, and to this extent it was attributed to the gradual drying-out of the upper part of the swamp—and consequent shift of the breeding centre towards the outer control huts (this drying out also accounted for the gradual reduction in the size of the *A. funestus* population). There was a decline in the percentage of ♀ *A. gambiae* in the experimental catch when compared with the inner control catch before and after clearance from 36 per cent. to 32 per cent. respectively. This decline was of the same order as the decline in the same ratios in the case of ♀ *A. funestus*. The two declines indicate that the cleared area attracted 10 per cent. less of the local Anopheline population after clearing of the bush; these small declines, which are probably not statistically significant, are quite insufficient to justify the use of bush clearance as an anti-malaria measure; moreover it cannot be proved that they were a consequence of the bush clearing, since there was evidence that the catch from the inner control hut increased gradually during the 7 weeks of the experiment, and such an increase would account for this small difference. The proportion of ♂ *A. funestus* that entered the inner control hut mounted gradually during the experiment, which indicates that this hut became, relatively, a more favoured resting place for male Anophelines, and therefore provides reason for believing that its attractiveness to females may also have increased.

The experimental catch of ♂ *A. funestus* when compared with the catch in the outer control before and after bush clearance was 318 per cent. and 314 per cent. respectively. I consider that this evidence of absence of change in the behaviour of the male mosquitos after bush clearing is of considerable importance because the male has no special incentive to enter the cleared area, and any reduction in Anopheline infestation after clearing should, therefore, first affect the behaviour of the male Anophelines.

The Mosquito Catches during Bush Clearance.

Examination of Table I shows that there was a very marked drop in the number of mosquitos which entered the experimental area while bush clearing was in progress. The ratios of the room averages of the experimental and inner-control catches declined from 77 per cent. to 29 per cent. in the case of ♀ *A. funestus*, so that based on this index the catch within the cleared area during clearance was only 38 per cent. of that before clearance. The ratio of the room averages of the experimental and the outer control catches declined from 167 per cent. to 45 per cent., so that based on this index the catch during clearance was only 27 per cent. of that before clearance.

The behaviour of ♀ *A. gambiae* was similar, for in this case the ratio of the experimental catch to the inner control catch declined to 28 per cent. of its former value, and that of the experimental catch to the outer control catch to 20 per cent.

The ♂ *A. funestus* showed a decrease in both ratios to 50 per cent. of their former value.

These results show that during the bush clearance the proportion of the female Anopheline population which entered the cleared area dropped to between one-third and one-quarter of its former value, and the proportion of male Anophelines to one-half.

The fact that males continued to enter the cleared area, and the reduction of their numbers was not as great as the reduction in the numbers of the females, indicated that the supposition that the area had become repellant to mosquitos would not completely explain the results.

TABLE I.

Mosquito catches before, during, and after bush clearance.

	♀ *A. funestus*								
	Before clearance				During clearance	After clearance			
Date	Jan. 27–Feb. 2	Feb. 3–9	Feb. 10–16	Total	Feb. 19–23	Total	Feb. 24–Mar. 2	Mar. 3–9	Mar. 10–16
Number of daily catches	8	7	7	22	5	21	7	7	7
Experimental Catch (3 rooms)	598	651	316	1,565	81	935	427	386	122
Inner Control Catch (1 room)	217	338	125	680	93	437	143	216	78
Outer Control Catch (2 rooms)	217	321	88	626	112	337	152	143	42
Room Average. Experimental/Outer Control	184%	133%	238%	167%	45%	184%	186%	180%	200%
Room Average. Inner Control/Outer Control	200%	210%	284%	217%	164%	260%	187%	302%	390%
Room Average. Experimental/Inner Control	92%	64%	84%	77%	29%	71%	100%	60%	53%

	♀ *A. gambiae*			♂ *A. funestus*			♂ *A. gambiae*		
	Before clearance	During clearance	After clearance	Before clearance	During clearance	After clearance	Before clearance	During clearance	After clearance
Experimental Catch (3 rooms)	126	8	75	162	7	33	12	0	0
Inner Control Catch (1 room)	115	27	79	146	14	50	11	1	6
Outer Control Catch (2 rooms)	231	81	196	34	3	7	14	4	2
Room Average. Experimental/Outer Control	36%	7%	26%	318%	155%	314%	Numbers not significant. No conclusions drawn.		
Room Average. Inner Control/Outer Control	100%	67%	81%	857%	390%	1,430%			
Room Average. Experimental/Inner Control	36%	10%	32%	37%	17%	22%			

TABLE II.

Daily catches of female *A. funestus* before, during, and after bush clearance.

	Before clearance							During clearance				
Date February	10	11	12	13	14	15	16	19	20	21	22	23
Experimental Catch (3 rooms)... ...	72	50	54	48	43	21	28	8	23	14	15	21
Inner Control Catch (1 room)	25	18	14	21	20	7	20	31	12	23	12	15
Outer Control Catch (2 rooms) ...	31	6	5	4	27	12	3	15	56	15	10	16
Room Average. Experimental / Inner Control	96%	93%	129%	76%	72%	100%	47%	9%	64%	20%	42%	47%
Room Average. Experimental / Outer Control	155%	555%	730%	800%	106%	117%	620%	36%	27%	62%	100%	87%

	After clearance						
Date February	24	25	26	27	28	1 Mar.	2 Mar.
Experimental Catch (3 rooms)... ...	21	46	78	76	75	54	77
Inner Control Catch (1 room)	10	21	29	11	36	25	11
Outer Control Catch (2 rooms) ...	12	23	32	31	14	20	20
Room Average. Experimental / Inner Control	70%	73%	90%	230%	69%	72%	234%
Room Average. Experimental / Outer Control	117%	133%	162%	163%	357%	180%	253%

Examination of Table II shows that the decline persisted throughout the whole five days of bush clearance, but that it was most marked on the first three days; then the proportion of ♀ *A. funesius* that entered the experimental huts was lower than that recorded on any other day during the seven weeks of the experiment. On the first two days most of the vegetation in the vicinity of the huts was cut, and the vegetation dried very rapidly in the hot sun (so that the whole area could be burnt off within five days). I therefore consider that the reduction in the number of mosquitos was due to some obscuring odour, which emanated from the cut bush and masked the attracting scent from the human inhabitants of the experimental huts. Such an odour would produce its maximum effect on the first days of clearance, and would be completely eliminated as soon as the bush was burnt, and it would therefore explain the recorded behaviour of the mosquitos.

The Effect of Cut Bush on Host Selection by Anophelines.

The present experiments were conducted in conjunction with another experiment which was one of a series made in order to determine the relation between Anopheline behaviour and human population density. For this experiment 3 of the 7 natives in the experimental huts slept in one end room of hut Y, and one other native in the other end room. The natives occupied the huts in rotation, in order to cancel the effects of variation on human attractiveness. During 35 days (3rd-16th February and 24th February-16th March) before and after bush-clearing, the average catch of ♀ *A. funesius* from the 3 men was 68·1 per cent. of the total catch from all 4 men, and on only 6 of these 35 days did they obtain less than 60 per cent. of the total catch; but on the 5 days during bush clearance the average catch of the 3 men was only 54 per cent. of the total catch from all 4 men, and on 4 of these 5 days they obtained less than 60 per cent. of the total catch. Applying a test of significance, for this distribution $\chi^2 = 6{\cdot}97$, with 1 degree of freedom, and there is therefore less than 1 chance in 100 that this distribution was random.

This result indicates that the Anophelines at this period showed much less discrimination between the hut containing one man and the hut which contained three men. This reduction in the power of discrimination between quantitative stimuli, combined with a reduction in the degree of infestation, provides further evidence in favour of the hypothesis that the scent of the humans was masked by some odour from the cut and withering bush.

Effect of a Screen of High Bush on Anopheline Entry.

This experiment was conducted at Aberdeen, near Freetown, Sierra Leone, among a mosquito population consisting mainly of *A. melas* (Ribbands, 1944 *b*; 1946). Seven small huts were built close to the breeding ground, and 4 natives slept regularly in separate huts, in rotation, in order to eliminate the effects of variation in human attractiveness. Six of these huts were built in a clearing, and the seventh one was built 25 yards away from the nearest of these huts, and 10 yards within a belt of dense bush which grew 10-15 ft. high. This hut was approachable only by a narrow path overhung with bush (*see* fig. 1, Ribbands, 1946). The catch from the hut in the bush was compared with the same night's catch from the nearest occupied hut in the clearing. The experiment was discontinued after a short while because the hut became " ju-ju ", and the natives refused to sleep in it. The " ju-ju " had no detectable effect on the Anophelines.

Catches were made on 14 days between 27th August and 15th September, 1941, 315 ♀ and 3 ♂ *A. melas* being collected from the hut in the bush, and 319 ♀ and 1 ♂ *A. melas* from the nearest hut in the clearing. There was considerable variation in the proportion caught in the two huts on different nights, this variation being largely attributable to the differences in the attractiveness of

the sleepers who changed huts in rotation so that this consideration could be disregarded when assessing the results. The percentage of the total catch which was attracted to the hut in the bush was calculated for each separate night, and the average percentage attracted by this hut over the 14-day period was 47·4 per cent. of the total catch. Hence the dense screen of bush had no effect on the Anopheline infestation.

Summary.

1. Two huts were selected which were surrounded by dense bush, which varied in height from 4 to 15 feet. After elimination of this bush within a radius of 140 yards from these huts, the proportion of the population of ♀ *A. funestus* and ♀ *A. gambiae* attracted to them was at least 90 per cent. of the proportion which reached them before the bush clearance. This result indicates that bush clearance is not a justifiable measure for reducing Anopheline infestation. Even the male Anophelines entered the cleared area in the same proportion as they did before clearance.

2. While bush clearance was in progress there was a temporary sharp reduction in the infestation, and the proportion of the female Anopheline population attracted declined to between one-third and one-quarter of the proportion attracted before clearance. The proportion of males dropped by one-half. At the same time the ♀ Anophelines were apparently much less able to discriminate between quantitative olfactory stimuli. Both effects are attributed to masking by an obscuring odour from the cut and withering bush.

3. There was no difference between the numbers of *A. melas* attracted to a hut screened by a 10 yard thick belt of dense high bush and the numbers attracted to an identical hut in the adjacent clearing 25 yards away.

Acknowledgements.

I am pleased to acknowledge my indebtedness to Lt.-Col. G. K. Fulton, then Assistant Director of Hygiene, West Africa Force, who provided for me the facilities which made the Gold Coast work possible, and to Mr. P. Slater, Malaria Superintendent, Freetown, who enabled me to conduct the experiment at Aberdeen.

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TESTS ON CLOTHING IMPREGNATED WITH DDT AS AN ANTI-LOUSE MEASURE.

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Introduction.

It would be of the greatest value in the control of typhus fever if, by impregnation with some substance, clothing could be rendered permanently toxic to the body louse. At present the only one that approaches this ideal with a reasonable degree of safety appears to be dichloro-diphenyl-trichloro-ethane, commonly abbreviated to DDT. Various other substances have been suggested, such as halogenated phenols (Moore & Hirschfelder, 1919), pyrethrum (Kalabukhov, 1943), dixanthogen (Soboleva, 1942), and the thiocyanate, Lethane (Busvine, 1945).

Bushland *et al.* (1944) have published a short account of the use of DDT for impregnating clothing. They gave few details and made no mention of relevant louse biology. The present paper describes simple laboratory biological tests carried out to appraise the usefulness of clothing impregnated with DDT. Most of the fabrics used were impregnated, chiefly with a solution of DDT in White Spirit, at a Ministry of Supply Experimental Station where all the chemical side of the work was done.

Breeding and Testing Methods and Biological Considerations.

(i) *Method of breeding body-lice for tests.*

The lice, *Pediculus humanus corporis*, were bred in small metal boxes which were kept against the legs of volunteers by pieces of sock. They fed through bolting silk which covered openings in the boxes (*cf.* Buxton, 1939) and oviposited on pieces of tape. Boxes were removed at night. Several volunteers bred lice, so there was a possibility of considerable variation.

(ii) *Reactions of the body-louse to DDT poisoning.*

The following chronological series of reactions are shown by lice on impregnated fabrics. A common reaction at first is the dispersal of the lice over the available surface; while lice on control fabrics tend to huddle together, those on experimental fabrics are usually found, after a short time, to be dispersed and still. Later an occasional leg tremor is observable; and this condition is followed by one of violent ataxia, which is particularly noticeable in the legs; the male genitalia are frequently everted. After the condition of ataxia the lice become helpless, exhibit a slight leg tremor and are usually shrivelled and discoloured. Finally there is complete immobility.

In the experiments described, lice have been classified as *alive*, if they appeared normal; *affected*, if they were showing any clear signs of toxaemia; *dying or moribund*, if they were helpless; and *dead*. Usually "alive" and "affected" were grouped as alive and the others as dead.

It is interesting to note that Läuger, Martin and Müller (1944) have suggested that DDT may very likely enter insects through the cuticle of the sense organs. It seems possible that the contact sense organs, which are distributed all over the body surface of the louse (Wigglesworth, 1941), may be the first organs to be affected by DDT, as is suggested by the loss of the thigmotactic response.

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(iii) *Methods of testing.*

The simplicity of the tests was justified on account of the inherent variations likely in the biological material, the need for a rapid appraisal of the potentialities of DDT and, subsequently, by the consistency of the results themselves. Two methods were used.

Method 1.—Lice were confined in standard metal boxes with pieces, 2 cm. × 3 cm., of the fabric under test. (Pieces were normally cut from the region of the armpit when garments were tested.) The boxes were kept against the leg as already described. Observations were made after approximately 24, 48 and 96 hours, and fabrics assessed as:—

Very effective if louse mortality was complete at the 24 hr. count;
Effective if louse mortality was complete at the 48 hr. count;
Moderately effective if louse mortality was complete at the 96 hr. count;
Slightly effective if louse mortality was 50 per cent. or more at the 96 hr. count;
Not effective if louse mortality was less than 50 per cent. at the 96 hr. count.

Method 2.—By means of inverted glass dishes, lice were made to crawl on impregnated fabrics. Conditions of temperature, etc., could be controlled and regular observations easily made.

Precautions taken in tests.

Tests were standardised as much as possible by adopting the following precautions. Adult lice were used in all routine tests. Each test was regarded as a separate entity and lice from the same sources were, as far as possible, equitably divided among the sample populations. Several fabrics were tested in each experiment and, in addition, fabrics of known insecticidal power were included in most experiments for comparison. In this way assessments of the chemical content of DDT in fabrics could be made with a fair degree of accuracy. A control was also included in most experiments. In view of the highly toxic nature of DDT, hands, bench, glassware and instruments were kept scrupulously clean. Metal boxes that had been previously used were soaked twice in ethylene dichloride and resupplied with fresh bolting silk. Most of the experimental boxes were kept on the writer's leg, but two tests on legs of colleagues indicated that no error was introduced in this way.

Eventually there were three strains of lice in use. Observation suggested that there was no marked difference in susceptibility to DDT between them, nor did age appear to be an important factor within reasonable limits, but the simplicity of the tests precluded nice distinctions. Young adults were preferred in most experiments. The results have been remarkably consistent, and variations in resistance have been frequently checked by comparisons with standards.

It was found convenient to express the dosage on fabrics as a percentage weight of DDT per unit weight of fabric. Thus, on angola shirting 1 per cent. DDT is equivalent to 0·2 mgm. per square centimetre of fabric.

(iv) *Difference in susceptibility to DDT of males, females and nymphs of the body louse.*

Table I gives data derived from an experiment in which lice crawled on fabrics for short periods (up to 2 hours) and were counted 48 hours later. Each vertical column gives the results with a sample population. Figures similarly derived from other experiments, in which a variety of fabrics were tested by method 1, are given in Table II. Clearly, if we consider Tables I and II together, males and females differ very little in susceptibility, but both are more susceptible than second- and third-stage nymphs (*cf.* Table VIII). These differences would be important only where the concentration of DDT was low (less than 0·1 per cent.) or the exposure time short as is shown in Table I (short exposure time) and Table II

experiment 6 (long exposure time and low dose). An experiment in which lice were tested on a piece of 1 per cent. shirting by method 2 showed that after 24 hours' contact with the fabric the mortality in first- and third-stage nymphs was not markedly different but first-stage nymphs (" larvae " of some authors) exhibited the various reactions of DDT poisoning sooner, and this suggests that they are at least a little more susceptible.

TABLE I.

Effect on lice of crawling on impregnated fabrics.

								Mortality
Females	Alive ...	0	1	3	0	1	0	
	Dead ...	5	4	2	5	4	5	$=\frac{25}{30}=83\%$
	Total ...	5	5	5	5	5	5	
Males	Alive ...	3	0	2	0	2	0	
	Dead ...	2	4	3	5	4	5	$=\frac{23}{30}=77\%$
	Total ...	5	4	5	5	6	5	
Nymphs ... ... (2nd and 3rd stage)	Alive ...	2	1	4	1	4	2	
	Dead ...	3	4	1	4	1	3	$=\frac{16}{30}=53\%$
	Total ...	5	5	5	5	5	5	

Time of contact—2 hours. Counts made 48 hours later.

The use of adults in routine tests is felt to be justified as they are not markedly more susceptible than the immature stages. They are easier to handle, give quicker results and are more convenient for the maintenance of stocks.

TABLE II.

Effect on lice of crawling on a variety of impregnated fabrics.

—	Periods in hours of confinement in standard boxes									Means
	24	24	24	24	48	24	48	96	96	
Males ...	82% (28)	84% (25)	33% (18)	100% (21)	100% (21)	63% (24)	100% (24)	63% (24)	72% (25)	77%
Females ...	68% (28)	100% (15)	22% (18)	94% (36)	100% (36)	67% (48)	98% (48)	43% (30)	44% (25)	71%
Nymphs (2nd & 3rd stage)				83% (60)	97% (60)	31% (72)	86% (72)	27% (63)		65%
Control ...	0% (8)	11% (9)	0% (13)		0% (20)		15% (20)	10% (19)	0% (10)	5%
Experiment number	1	2	3	4		5		6	7	

Mortalities are given in the body of this table.
Figures in brackets give numbers of insects on which mortality is based.
Tests in which the mortality of all lice was 100% are not included in this Table. The test pieces used in experiments 6 and 7 were of very low DDT content (as is obvious, for they were at most " slightly effective "=less than 0·04%). General observations and other results confirm these findings. Two readings are given for each of experiments 4 and 5.

It is common to find very unequal proportions of the two sexes in louse populations (Buxton, 1939). Sex equality in experimental samples could not, therefore, always be attained, but the distribution was equitable in samples in any one experiment.

Factors likely to Affect the Action of DDT.

(i) *The effect of nap.*

The object of these tests was to ascertain if raising the nap of a fabric made more DDT available and consequently made it more insecticidal than similar fabrics in which the nap had been pressed.

TABLE III.

Relative toxicities of pressed and unpressed fabrics.

Fabrics	Lice	
	Adults	2nd and 3rd stage nymphs
Pressed	68% (31)	32% (31)
Unpressed	61% (33)	52% (31)
Control	0% (21)	0% (31)

Mortalities (totals for three tests) after crawling for about 24 hours at 30° C. (86° F.). Figures in brackets give the number of insects upon which the mortality is based.

Two pieces were removed from an angola shirt which had been found by chemical analysis to contain 0·04 per cent. DDT approximately. They were tested by method 2 and found to be equally insecticidal. The nap was then raised in one piece by wetting it and allowing it to dry, whilst the nap in the other piece was flattened by wetting it and allowing it to dry under a piece of clean weighted glass. The DDT on the fabrics was thus not disturbed by being brushed or heated by an iron. The pieces were tested by method 2 with the results given in Table III. The nap on both fabrics was then raised again and they were retested, the results being given in Table IV.

These results were obtained with pieces of fabric which were "moderately effective" (0·04 per cent. DDT): *i.e.*, all adult lice dead after continuous contact for 96 hours (*see* p. 44). With the numbers of lice used, the inherent variations in them, and the low concentration of DDT, variations in the mortalities are to be expected. The difference in mortality is marked only with the immature lice, and it is possible that differences in nap may be the cause. It seems likely from the results given that the difference in mortality would be small after 96 hours in the standard box tests. Big differences are not to be anticipated with impregnations of 0·1 per cent. and over, and an experiment in which adult and immature lice were all dead or dying after crawling for 24 hours (method 2 at 30°C.) on a 0·1 per cent. fabric confirmed this.

Clearly it is very unlikely that differences in nap are important.

TABLE IV.

Relative toxicities of unpressed fabrics one of which had been previously pressed.

Test No.	1	2	Average mortality for tests 1 and 2
Period of crawling	24 hours	48 hours*	...
Piece previously pressed ...	40% (10)	91% (11)	66%
Piece previously unpressed...	70% (10)	66% (12)	68%
Control	10% (10)	0% (12)	5%

* Test partly at laboratory temperature.
Mortalities of 2nd and 3rd stage nymphal lice after crawling at 30° C.
The nap was raised on both fabrics.

(ii) *Loss of insecticidal power due to friction.*

It was noticed that pieces of fabric which were used in tests more than once appeared to lose insecticidal power if they were stored in paper envelopes in the interval between the tests. Experiments indicated that the interiors of envelopes that had stored some large pieces of fabrics were insecticidal, and that loss of insecticidal power from the fabrics was not due to lice walking on them.

Most pieces of paper that have been used to wrap angola shirting can be seen to be sprinkled with numerous small fibres of the fabric. It is likely that these are the cause of loss of insecticidal power in the fabric and gain by the paper. Transfer of insecticidal power, referred to later, is also probably due to transfer of insecticidal fibres.

(iii) *Sleeve test.*

From the literature it seems that American investigators test anti-louse insecticides by confining lice on the arm under a sleeve. To see how the box method used here compared with sleeve tests, a sleeve was cut from a shirt (0·04 per cent. DDT) and attached to the writer's arm by adhesive tape: lice were confined under the sleeve, which was then covered with surgical silk. Control lice were put in a standard box with a piece of adhesive tape, folded to prevent adhesion of the lice, and the box was carried on the leg in the usual way. Seven females, two males and five nymphs were put in the sleeve and 48 hours later the sleeve contained one live female, two live but affected males and one seriously affected nymph; whilst six females, two males and one nymph were dead and one had been crushed. At least two nymphs had become adult in the 48 hours. There were 14 living lice in the control tin. The four live lice from the sleeve were put in a box on the leg and 48 hours later 2 were dead and 2 alive.

The sleeve was from a "moderately effective" garment (0·04 per cent. DDT), and the result obtained is essentially similar to that obtained with the box method. The box method is simpler than the sleeve method.

DDT as an Insecticide.

(i) *Preliminary tests.*

These tests were carried out before the elaboration of the final testing method but they have been very largely confirmed by the results of other tests. Some of the garments were later used as standards for checking the susceptibility of biological material.

The garments, angola shirts and woollen vests, were tested by method I and the results are given in Table V.

TABLE V.

Preliminary Tests with DDT.

1 Nominal initial % DDT	2 Type of garment	3 Treatment	4 Number of launders	5 Biological assessment after treatments in Cols. 3 and 4	6 Chemical assay of % DDT remaining after treatments in Cols. 3 and 4. Means.
1	Shirts	Worn 3 weeks by sedentary workers	5	Moderately effective to effective (5 tests on 5 garments)	0·13 (5 garments)
1	Vests	Ditto	5	Slightly effective (5 tests on 4 garments)	Approx. 0·07 (3 garments)
1	Shirts	Worn 7 weeks by sedentary workers	9	Not effective (2 tests on 2 garments)	0·08 (1 garment)
1	Shirt	Worn 360 working hours by stoker	5	Moderately effective (1 test on 1 garment)	—
1	Shirts, vests and pants	Worn 3 weeks night and day	0	Very effective	—
1	Shirts	Twice autoclaved at 234° F. (129° C.) for 20 minutes	0	Effective (1 test)	0·46 (1 garment)
0·5	Shirts and vests	Worn 2 weeks by sedentary workers	Shirts 3 Vests 4	Moderately effective (5 tests on 5 garments)	—
0·5	Shirts and vests	Worn 5 weeks by sedentary workers	7	Not effective (8 tests on 8 garments)	About 0·05 (9 garments)

A piece of angola shirting impregnated with 1·2 per cent. DDT proved to be completely insecticidal after it had been boiled for half an hour in soap and water, a treatment which converted it into a coarse shrunken piece of fawn-coloured fabric.

Insects were confined with DDT in airtight glass jars in such a way that they could not come into direct contact with it in order to determine whether DDT had any toxic vapour phase. It was not found to have any, though certain unrefined samples might give off volatile impurities of a toxic nature.

(ii) *Comparison of biological assessment and chemical analysis.*

A method of chemical analysis was elaborated by a Ministry of Supply Establishment engaged on the impregnation work, and some garments that had been tested biologically with lice and assessed by method I were sent for chemical analysis. The results are co-ordinated in Table VI.

The results given in Tables V and VI indicate that 0·1 per cent. weight for weight DDT is likely to be the minimum safe degree of impregnation as an anti-typhus measure.

TABLE VI.

Comparison of biological assessments of toxicity with chemical content.

Assessment by biological assay method 1	Chemical analysis % DDT wt/wt approximately				
	Less than 0·04	0·04–0·08	0·09–0·19	0·2–0·5	More than 0·5
Not effective	8	2	1	0	0
Slightly effective	2	2	1	0	0
Moderately effective...	0	1	1	0	0
Effective	0	0	3	3	1
Very effective...	0	0	0	1	2

Figures show the number of garments falling in each chemical/biological group.

(iii) *Assessment of chemical content by biological tests.*

In the fully elaborated method pieces of standard garment of known DDT content were included in each test, and from them, by comparison, assessments of the DDT content of other garments could be made with a fair degree of accuracy. Table VII gives results of tests by method 1 in which the DDT content of tested garments was assessed by comparison with standards, and variations in susceptibility between louse samples were allowed for. The assessments in these tests were made without any knowledge of the actual chemical contents of DDT, information which was supplied later. It is noteworthy that the results of tests on these two garments (impregnated 1 per cent. DDT, worn 4-6 weeks and laundered 3-4 times) fall into line very well with those given in Tables V and VI.

TABLE VII.

Accuracy of biological assessments compared with subsequent chemical analyses.

Garment	Biological assessments					% DDT Content	
						Predicted	Actual
No. 4 armpit ...	Effective	Moderately effective	Effective	Effective	Effective	0·04–0·1%	0·1%
No. 4 tail ...	Moderately effective	Moderately effective	Effective	Effective	Effective		
No. 10 armpit ...	Effective	Effective	Effective	Very effective	Very effective	0·1–0·2%	0·2%
No. 10 tail ...	Very effective	Effective	Effective	Very effective	Very effective		
Standard No. 1 (= effective)	Very effective	—		—	—	—	0·1%
Standard No. 2 (= slightly effective)	Moderately effective	Slightly effective		Moderately effective	Moderately effective	—	Less than 0·04%
Control	No mortality	Mortality : low		No mortality	No mortality	—	0%
Insects per sample	8	8		12	10	—	—

N.B.—In each experiment different pieces of shirts 4 and 10 were used, 10 pieces of each garment being tested in all.
No. 4 : 1% DDT shirt worn 6 weeks, washed by hand 3 times.
No. 10 : 1% DDT shirt worn 4 weeks, washed by hand 4 times.

(iv) *Minimum dose for complete mortality.*

These tests were designed to ascertain for how long lice must crawl on impregnated fabric to pick up a lethal quantity of DDT.

Some pieces of angola shirting of known DDT content were tested by a variation of method 2. The lice were sorted into glass capsules and thence, after being temperature conditioned for about ten minutes, were tipped on the fabrics where they crawled at a temperature of 30°C. After suitable intervals, the lice were removed, care being taken not to remove pieces of nap as well, and returned to the glass capsules which had now each a piece of black tape for the insects to cling to. The capsules were kept at laboratory temperature (about 20°C.), and the mortality noted about 48 hours later. Results are given in Table VIII.

TABLE VIII.

Effect of DDT content on mortality rate.

Contact time in minutes	Type of lice	Mortalities after crawling on:			
		0·1% fabric	0·5% fabric	1·0% fabric	1·75% fabric
0–35	Adults	38% (13 lice in 2 tests)	75% (24 lice in 3 tests)	92% (46 lice in 6 tests)	100% (64 lice in 7 tests)
	Immature	...	...	37% (16 lice in 2 tests)	57% (26 lice in 3 tests)
36–70	Adults	57% (28 lice in 3 tests)	61% (18 lice in 2 tests)	100% (31 lice in 3 tests)	100% (31 lice in 3 tests)
	Immature	28% (14 lice in 2 tests)	14% (14 lice in 2 tests)	85% (26 lice in 3 tests)	100% (16 lice in 2 tests)
80–160	Adults	75% (40 lice in 4 tests)	95% (41 lice in 4 tests)	...	...
	Immature	85% (28 lice in 3 tests)	84% (25 lice in 3 tests)	100% (8 lice in 1 test)	100% (9 lice in 1 test)

Control mortality was zero in all tests except one: mortality was 1/14.
Immature lice were 2nd and 3rd stage nymphs.

Mortalities were derived from a number of experiments carried out on different days each of which consisted of a number of tests, of which one at least was made on each of the four fabric samples. The lice were given no opportunity of feeding after exposure to impregnated fabric, and it must be remembered that they were alive when removed from the fabrics. The tests thus simulated conditions in which lice crawl on to impregnated clothing and subsequently leave their host. From what was said on p. 43, it is clear that, under most conditions, lice that are going to die would be unable to feed for some time prior to death because of the vigorousness of the ataxia produced by DDT.

The results have been abundantly confirmed in further wearing trials. One garment which had become insecticidal through contact with an impregnated garment was chemically analysed and found to have only a trace of DDT. This was not in line with the results of biological tests. The most probable explanation of this apparent anomaly is that the transfer of insecticidal power is most likely to be due to the transfer of the innumerable small fibres always shed by angola shirting. As in this instance the fibres came from a highly insecticidal garment, they would be very toxic to lice and would lie on the surface of the untreated fabric, which would then have a trace of DDT on one surface but none within it and none on its other surface so that all the DDT on the fabric would be available to kill lice and none of it would be wasted within the matrix of the fabric.

Discussion.

The conclusion that insecticidal power is transferred from garment to garment and is, to some extent, lost by storage in rough surfaced paper, is of considerable importance, as, apart from its practical value, it indicates how DDT is lost, and affords an explanation of the different losses caused by different wearers. It is likely that the amount of body hair and friction due to muscular exercise are more important factors in DDT loss than sweating. Further the indications are that it is loss of nap rather than loss of actual DDT from garments that is the chief obstacle to their permanent impregnation.

The fact that carefully conducted biological tests of a simple nature can be used to predict the chemical content of garments is of great interest as it could probably be elaborated to form a useful field test for use by scientific personnel in typhus areas.

The laboratory work has been done with a view to the elimination of typhus epidemics by the reduction of louse populations. The rapid attainment of a high louse mortality has, therefore, not been regarded as of primary importance. It is worth noting that with any insecticide a typhus-infected louse might defaecate before dying and the infected faeces cause typhus in the host. For these reasons it has been possible to suggest a degree of impregnation as low as 0·1 per cent. DDT as the minimum for anti-typhus control. It may be that this is too low a figure, but only experience in the field can properly decide. A higher dose would clearly be needed by those in regular contact with the very lousy. Peacock (1916) working among soldiers in the trenches, decided that the time of transfer of lice was mainly during periods when men slept in close proximity. If impregnated shirts are issued to all soldiers, then any gross lousiness will be eliminated by the heavily impregnated shirts (1-2 per cent.) when first donned (or by disinfestation) and any small, later, cross infestations will be eliminated by the same shirt after its DDT content has been lowered in wear, etc., provided that the soldiers do not come into close contact with very lousy civilians.

MacLeod and Craufurd-Benson (1941) found that two-thirds of the total louse population was in the seam areas and that most lice were on the two surfaces of the innermost undergarment, further that female lice on the innermost aspect of garments were relatively most numerous in the seams and in the armpits, the latter being a favourite oviposition site, and that the fork of the trousers appeared to be a focus of infestation. These conclusions are of practical importance when deciding which undergarment or how many types of undergarment should be impregnated. The same workers also found that immature lice were usually more numerous in louse populations than the adults. Thus, when making assessments in the field the slow action of DDT must be borne in mind.

The suggestion that DDT may enter insects through the cuticle of the sense organs was made by Läuger, Martin and Müller, and the view that it may enter the louse through the tactile sense organs is put forward tentatively here as a contribution to the theories on the mode of action of DDT. The first observable sign of poisoning in the louse appears to be the loss of the thigmotactic response. The fate of the DDT in the insect's body cavity is a matter for speculation, but perhaps hydrotropy plays a part.

Summary.

Simple tests have been done to appraise the value of garments impregnated with DDT as an anti-louse measure. It is very toxic to the body louse but its action is relatively slow. Woollen and cotton fabrics can be impregnated with it.

No estimate can be given of the precise length of the insecticidal life of a garment because of variations in wear, etc. But garments have been found to have 0·1 per cent. DDT remaining after five launders and three weeks' wear. The minimum safe degree of impregnation as an anti-louse measure appears to be 0·1 per cent. By the use of simple biological tests reasonably accurate assessments of the chemical content of garments can be made.

DDT is to some extent resistant to high temperatures. It is suggested that the chief cause of loss of insecticidal power is due to loss of nap. Impregnated garments transfer their insecticidal power to unimpregnated garments kept in contact with them.

Results show that subsequent mortality is complete or very high among lice which have crawled for three hours on fabrics impregnated with DDT at rates between 0·1 and 1·75 per cent. Signs of poisoning may take six hours to be manifested in the louse.

The results obtained with a sleeve test compared very closely with those obtained by the box method used chiefly in this work.

The theory is put forward that DDT enters the body louse through its tactile sense organs.

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THE MOSQUITOES OF BWAMBA COUNTY, UGANDA.

IV.—Studies on the Genus *Eretmapodites*, Theobald.

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During 1941 yellow fever virus was isolated from a human patient and from wild-caught mosquitoes in Bwamba County, Western Province, Uganda (Mahaffy & others, 1942). Bwamba is a heavily forested area lying between the Ruwenzori Mountains and the Semliki River, which forms part of the Uganda-Congo boundary. The topography and vegetation have been described in some detail in a previous communication (1945a). Following the isolation of virus, intensive entomological work was begun in Bwamba, and is still in progress. Much of the work has consisted of large-scale catches of adult mosquitoes in rain-forest and banana plantations, in a search for yellow fever virus. During these catches it was found that several species of the genus *Eretmapodites,* Theobald, were quite common in the forest, including some which are poorly or incompletely represented in museum collections, and a new species was also discovered. The object of the present paper is to describe the new and little-known material obtained in Bwamba, and to discuss what is known of the bionomics of the local species.

Eretmapodites is the only genus of mosquitoes confined to the Ethiopian Region (*i.e.*, Africa south of the Sahara), though 1 species, *E. quinquevittatus,* Theo., has also been taken in Madagascar, which is usually considered as belonging to a different zoogeographical area, the Malagasy Region. The genus is a small one and at the moment includes only 24 species and subspecies, though it seems probable that with the increase of mosquito study in Africa many new forms will be recognised. The genus is particularly well represented in Bwamba, where 1 new species and 7 known species and subspecies have been found to occur. Unfortunately most of the species are almost impossible to identify with certainty unless the immature stages or male terminalia are available for examination. The present study has not improved this position, as it has been found that several characters, formerly regarded as having specific diagnostic value, are not reliable.

The members of this genus are largely restricted to forest and other dense vegetation such as banana plantations, and this doubtless accounts for the scarcity of published records concerning their behaviour. The results of 24-hour catches made in Bwamba and discussed in a previous communication (1945b), together with the results of routine day and night catches, have shown that the local species bite almost exclusively by day, with a marked peak of activity in the late afternoon. It is probably on account of this habit that *Eretmapodites* are scarce in catches recorded in the literature, for such have usually been made fairly early in the morning or else by night. Newstead (quoted by Edwards, 1941) noted that *E. quinquevittatus,* Theo., and *E. inornatus,* Newst. " fed viciously at five in the afternoon " and Hopkins (also quoted by Edwards) observed the day biting habit in the case of the *E. chrysogaster* group. Kerr (1933) believed that *E. chrysogaster,* Graham, did not readily bite man in nature, a mistaken conclusion, due to the fact that his work consisted mainly of night catches, made at times when this species is quiescent. The liking of this genus for human blood may be regarded as established by the fact that about 6,500 *Eretmapodites* (including all the local species) have been taken biting man in Bwamba.

Bauer (1928) successfully transmitted yellow fever to Rhesus monkeys by the bite of *E. chrysogaster.* Since the time of his experiments, the original *E. chrysogaster* has been subdivided into various species, and it is not possible to

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tell with which of these he worked. The point is probably academic and of no practical importance. Yellow fever virus has not so far been isolated from *Eretmapodites* taken in Bwamba, but recently three strains of a virus closely related to that of Rift Valley fever (and perhaps identical) have been isolated from mixed lots of *Eretmapodites* spp. collected in the uninhabited rain-forest. A certain amount of medical interest thus attaches to the genus, which may include transmitters of human and animal virus diseases.

Among the more interesting features of adult structure may be mentioned the extraordinary complexity of the male terminalia. This is perhaps necessitated by the peculiar and violent copulatory habits (noted by the writer in the case of *E. chrysogaster*). The male having established contact with the female, the latter almost immediately settles. The male now hangs head-downward, suspended solely by his terminalia, and may retain this position for over an hour, frequently quivering rapidly and violently throughout. Bauer, who collected much useful information about *E. chrysogaster* in the course of his transmission experiments, noted that this species will breed freely in small cages, and present work confirms his findings. In describing male terminalia Edwards (1941) uses the phrase " bent hairs " to describe certain peculiarly modified setae at the tips of the distal claspettes. As these are markedly bisinuous, the term " bent " seems rather unsuitable, and the writer prefers to refer to them as " sigmoid hairs ".

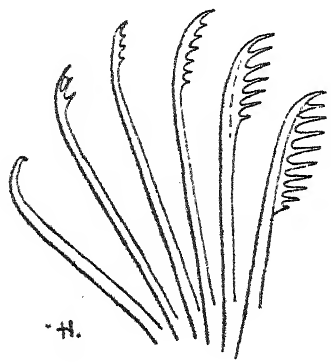

FIG. 1.—Modified hairs from the mouth-brushes of the larvae of *Eretmapodites* spp.

Bauer (*loc. cit.*) noted that the eggs of *E. chrysogaster* were laid in small numbers at frequent intervals, at the edge of the water, that they quickly sank, and that they did not survive drying. These observations have been found to apply to all the Bwamba species. The habit of depositing eggs in small numbers is probably due to the fact that *Eretmapodites* spp. usually oviposit in very small collections of water in fallen leaves, plant axils and snail shells.

All the larvae studied in Bwamba have been found to be predatory on other mosquito larvae, on the aquatic larvae of other small Diptera, and on small aquatic Oligochaetes and Nematodes. Bauer noted predatory habits among his *E. chrysogaster* larvae and J. O. Harper (private communication) observed similar behaviour in a Bwamba species closely allied to *E. dracaenae*, Edw. In general, however, the predatory nature of *Eretmapodites* larvae has received little attention, and published descriptions omit reference to an interesting modification of the mouth-brushes, connected with predatory activity. The larvae of six species examined in Bwamba have all been found to possess a group of thickened, comb-like hairs on the medio-ventral aspect of the mouth-brushes (fig. 1). The hairs resemble those found in the mouth-brushes of *Culex* (*Lutzia*) *tigripes*, Grp. & C., whose well-known predatory habits have been discussed by MacGregor (1927) and the writer (1942). An *Eretmapodites* larva, after seizing a victim, holds it between

the half-flexed head and the ventral surface of the thorax. The prey is consumed rapidly—a large larva may be devoured in about 10 minutes—and larvae are attacked even in the presence of abundant other food material. Predacity will be discussed further below, under the separate species.

The pupae of all the Bwamba species are very sluggish. They spend long periods submerged, sometimes lying on one side as if dead. The pupal phase is usually rather prolonged, and may last as much as 5 or 6 days in some species.

In discussing taxonomy it is convenient to divide the genus into 4 groups, based on the adult ornamentation. These groups, though useful, are rather artificial, as is shown by the fact that the larvae or pupae of 2 species may show close similarity while the adults differ widely in ornamentation. The groups used in the present paper may be recognised as follows:—

1. *E. chrysogaster* group.
   Scutum without ornamentation or almost so; *apn* silvery.
2. *E. inornatus* group.
   Scutum with a pattern of narrow yellow lines; *apn* silvery.
3. *E. quinquevittatus* group.
   Scutum with a pattern of much broader yellow lines or with a single median yellow line; *apn* silvery.
4. *E. oedipodius* group.
   Scutum with a pattern of broad yellow lines as in the *E. quinquevittatus* group; *apn* yellow.

The various Bwamba species may now be discussed in detail. The system of description follows that adopted by Hopkins (1936) and Edwards (1941) in the standard textbook " Mosquitoes of the Ethiopian Region ".

Taxonomy and Bionomics.

1. The *E. chrysogaster* group.

Three members of this group (*E. chrysogaster*, Graham, *E. semisimplicipes*, Edw., and *E. grahami*, Edw.) have been found to occur in Bwamba. It was expected that *E. intermedius*, Edw., might be present, as this species has been recorded from Uganda and the eastern Belgian Congo, but so far it has not been recognised.

The differentiation of members of this group has been a matter of difficulty throughout, particularly as some of the diagnostic characters proposed by Edwards have proved unreliable. The only certain method of identification is the examination of the male terminalia.

(*a*) *E. chrysogaster*, Graham.

The material studied consists of numerous specimens bred out in the laboratory or taken in the course of routine catches.

Larva.

Local specimens comply fairly closely with Hopkins' description. The colour of the integument, however, is always brownish and much darker than in other *Eretmapodites* larvae. The denticulate bosses or tubercles of the thorax and abdomen show great variation. At the one extreme are found very well-developed tubercles, heavily sclerotised, and with numerous well-marked denticles studding the surface. In the main, tubercles of this type resemble Hopkins' figure, but sometimes they are even longer and more nipplelike, the ratio of basal width to height being 1:1 or 1:1½. At the other extreme are found poorly developed

lightly sclerotised, rather flattened tubercles, with only a few poorly developed denticles, and with the ratio of width to height about $1\frac{1}{2}:1$ or even almost $2:1$. Obviously some environmental influence is at work here, as larvae with strong tubercles are commonest in forest leaf-pools, while plant-axil specimens usually have tubercles of the weak, flattened type. Larvae of *E. grahami* have been described as having characteristic comb-spines "thorn-like with only very minute basal denticles" (Hopkins). Unfortunately, it has been found that spines of this kind frequently occur in *E. chrysogaster,* and as in some cases all the spines of a larva may be of this type (fig. 2, 1-6), the form of the spines is not a reliable diagnostic

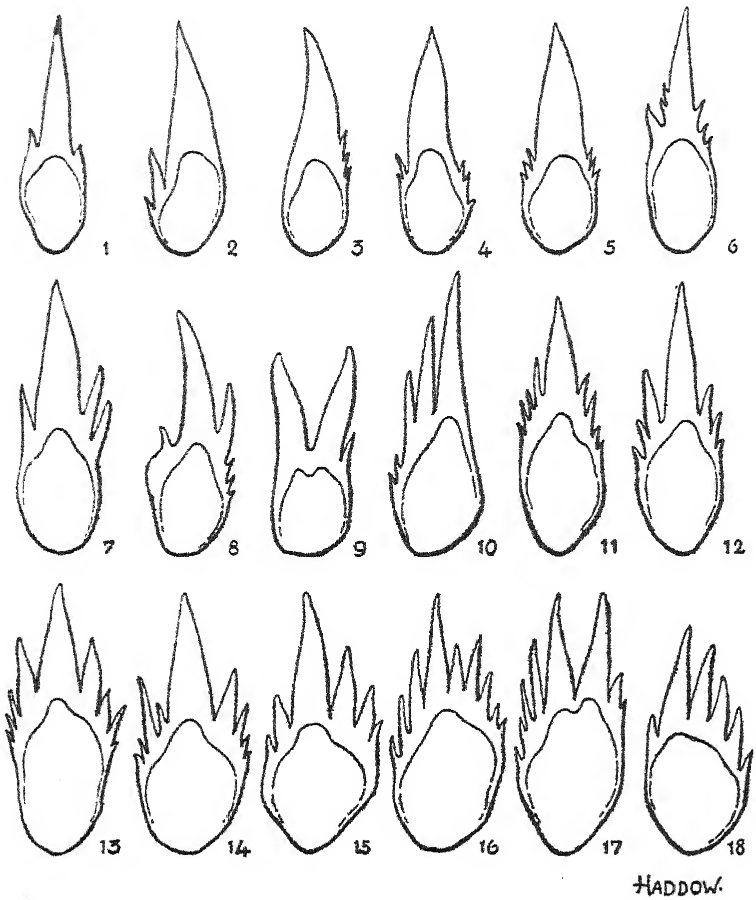

FIG 2.—Comb-spines from reared larvæ of *Eretmapodites chrysogaster* (specimens confirmed by examination of the male terminalia).

character. From this extreme the spines vary through forms with a large central tooth and a few well-developed basal denticles (fig. 2, 7-12), to types with the central tooth only a little larger than the others, which are numerous and strongly developed (fig. 2, 13-18). So far no larvae have been found with teeth of the extreme type figured by A. J. T. Terzi (in Hopkins); the central tooth is always easily recognisable, though it may sometimes be bifid (fig. 2, 9, 17). Once again it is obvious that environment has influence on structure for, while it is unusual to find a larva with teeth all of a single type, the simple thornlike forms are almost confined to larvae living in forest leaf-pools, while teeth with numerous secondary denticles predominate in plant-axil larvae.

Pupa.

As in Edwards' description.

Adult.

Mainly as in Edwards' description, but a few points call for comment. In the case of thoracic coloration much variation has been found to occur. In all cases, however, the yellow and black scales are fairly evenly mixed over most of the surface. The darkest specimens are at most medium brown and never have the blackish appearance of the next species. Occasionally a distinct yellow border to the scutum or a short median yellowish line in front of the scutellum (as noted by Edwards) has been found in Bwamba specimens. It is interesting to note that newly emerged adults often show a pattern of stripes resembling those of the *E. inornatus* group. These bands are integumental, rather faint, and very transitory. They disappear as the thorax darkens. They show, however, that there is a basic pattern throughout the genus, perhaps due to folding of the scutal integument within the pupal case. The pluming of the male hind tarsi agrees with Edwards' description and may be used with caution in distinguishing *E. chrysogaster* from *E. semisimplicipes.* The writer considers that Edwards' ratio of 7:8 for the relative length of the male palps and proboscis to be misleading. In many instances the palps are equal to or longer than the proboscis. This was the case in 34 of 71 males reared from *Colocasia* axils. It should be noted that the palps are relatively longer in the newly emerged male than in the fully dried specimen of 24 hours later. It is felt that this character should no longer be used in identification. In any case it is very difficult to take the measurement even in fresh specimens, as the palps curve strongly upward while the proboscis curves downward.

Field Notes.

The larvae are abundant in leaf-pools in forest and in banana plantations and are also common in plant axils. They have occasionally been taken in tree-holes, once in a ground-pool and once in a broken earthenware pot in a banana plantation. In all these rather exceptional cases dead leaves have been present in the water. The larvae have a pronounced browsing habit and are also active predators, as is shown by the following experiments:

Experiment 1.—Four large *E. chrysogaster* larvae were confined in separate tubes, with 20 ml. of the breeding water. To each tube 10 medium-sized larvae of *Aëdes* (*Stegomyia*) *simpsoni,* Theo., were added. During the next 24 hours 2, 7, 7, 8 *A. simpsoni* were devoured respectively—a mean of 6 per tube.

Experiment 2.—Four tubes were set up as described above, each with a small (2nd stage) *E. chrysogaster* larva and 10 *A. simpsoni* larvae, equal in size to the predator. In 24 hours 4, 5, 5, 6 *A. simpsoni* were devoured—a mean of 5 per tube. All the larvae were of about equal size at the beginning of the experiment, but at the end the *Eretmapodites* larvae were very much larger than the surviving *A. simpsoni.*

Experiment 3.—Four tubes were set up as described above, each with a large *E. chrysogaster* larva and 10 *A. simpsoni* pupae. Though the pupae were frequently attacked their tough integument and violent struggles usually allowed them to escape without harm. In 24 hours only 0, 0, 1, 2 were devoured.

Experiment 4.—Four tubes were set up as described above, each with 1 large and 10 small *E. chrysogaster* larvae. In 24 hours 0, 1, 1, 1 were devoured. The small larvae were constantly attacked by the large larvae and by one another, but their relatively tough integument and strong swimming movements rendered them fairly immune to attack.

Experiment 5.—Four tubes were set up as described above, each with 11 large *E. chrysogaster* larvae (11 so that the number should be the same as in the other experiments). They constantly seized one another, but after 24 hours only 0, 0, 1, 1 had been devoured, and these had probably entered the sluggish phase which precedes pupation.

Note.—In these and subsequent experiments medium-sized (3rd stage) larvae were used as prey. In some trials large larvae were used, but 1 or 2 usually pupated during the test, thus vitiating the result.

Thus the *E. chrysogaster* larva, while relatively immune to attack by members of its own species, probably controls to some extent the output of *A. simpsoni* larvae from plant axils. Larvae of the latter species have never been found in axils inhabited by *E. chrysogaster*. Larvae of *Harpagomyia taeniarostris*, Theo., *Uranotaenia ornata* var. *musarum*, Edw., and *Culex* (*Culiciomyia*) *nebulosus*, Theo.—all common in plant axils in Bwamba—are also attacked and destroyed.

Females bite man freely in the forest, and sometimes in banana plantations, almost always attacking the legs below the knee. Males are quite common in the forest undergrowth.

(*b*) *E. semisimplicipes*, Edw.

Material studied consists of wild-caught larvae (confirmed by male dissection), reared larvae, reared pupae, and reared and wild-caught adults.

Larva.

The larvae cannot be distinguished with certainty from those of *E. chrysogaster*, but some guidance is given by the fact that the integument is usually white instead of brownish. The comb has usually fewer spines than that of *E. chrysogaster* (about 12-20) but a good deal of overlap occurs.

Pupa.

The tentative characters proposed by Edwards as perhaps distinguishing the pupae from those of *E. chrysogaster* have been found unreliable.

Adult.

Mainly as in Edwards' description, but the following points should be noted. The integument of the thorax does not appear much darker than that of *E. chrysogaster* in fresh specimens; but the scutal scaling is very dark, and this has been found a good field character in both sexes. The general colour of the scutum appears a soft pastel-black to the naked eye. Under the microscope the scaling is seen to be mainly black, with a powdering of yellow. The pluming of the male hind tarsi complies with Edwards' description and figure. Once again it has been found that the relative length of the male palps and proboscis is variable. In a series of 12 males reared from *Colocasia* axils, only 8 had palps definitely shorter than the proboscis. Even in specimens with short palps, Edwards' ratio of 3:4 is considered to be too low.

Field Notes.

Larvae are quite common in forest leaf-pools and in plant axils. They have the same habits as those of *E. chrysogaster* and are active predators as is shown by the following experiment:

> Four tubes were set up exactly as in the *E. chrysogaster* experiments, each with a large *E. semisimplicipes* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 7, 8, 9, 9 of the latter were devoured—a mean of about 8 per tube.

Females are frequently taken biting in the forest, and males are common in the forest undergrowth.

(*c*) *E. grahami*, Edw.

Material studied consists of wild-caught adults only.

Larva and Pupa.

None has so far been taken in Bwamba. It is pointed out that the form of the larval comb spines is not a reliable specific character (*see* under *E. chrysogaster*).

Adult.

Wild-caught males from forest undergrowth have been identified by the absence of tarsal plumes and by examination of the terminalia. None has had any trace of a pale line on the underside of the proboscis. Some females of the *E. chrysogaster* group, taken biting in forest, have been assigned to this species as they lacked the pale line, which is usually clearly visible in Bwamba specimens of *E. chrysogaster* and *E. semisimplicipes*.

2. The *E. inornatus* group.

Two members of this group (*E. inornatus*, Newst. and *E. penicillatus*, Edw.) have so far been recognised in Bwamba. Study of the local material has shown that a good deal of variation in ornamentation exists, even among the progeny of a single female. It seems that several characters present used in adult identification (colour of the postspiracular bristles, direction of the silver markings on the 2nd abdominal tergite, and extent of the silver markings on the 7th abdominal tergite) must be considered unreliable. For example, both Bwamba species sometimes show a complete silvery band on the 7th tergite—supposedly a characteristic of *E. argyrurus*, Edw., and local specimens of *E. inornatus* have yellowish postspiracular bristles—a character supposed to be confined to *E. melanopus*, Graham, *E. forcipulatus*, Edw., *E. penicillatus*, Edw., and *E. tonsus*, Edw. Probably accurate final identification within this group must be considered as dependent on the examination of immature stages, the male terminalia, and perhaps the claws of the female foretarsi. It was hoped that the female terminalia might show specific characters, but examination of postgenital plates from *E. inornatus* and *E. penicillatus* has failed to reveal any difference of size, shape or chaetotaxy.

(*a*) *E. inornatus*, Newst.

The material studied includes numerous wild-caught specimens in all stages and a critical reared series comprising 23 larval skins, 8 whole larvae, 21 pupal pelts, 16 males, and 6 females. As the larva and pupa are now described for the first time, the series includes the paedotype.

Experiment 4.—Four tubes were set up as described above, each with 1 large and 10 small *E. chrysogaster* larvae. In 24 hours 0, 1, 1, 1 were devoured. The small larvae were constantly attacked by the large larvae and by one another, but their relatively tough integument and strong swimming movements rendered them fairly immune to attack.

Experiment 5.—Four tubes were set up as described above, each with 11 large *E. chrysogaster* larvae (11 so that the number should be the same as in the other experiments). They constantly seized one another, but after 24 hours only 0, 0, 1, 1 had been devoured, and these had probably entered the sluggish phase which precedes pupation.

Note.—In these and subsequent experiments medium-sized (3rd stage) larvae were used as prey. In some trials large larvae were used, but 1 or 2 usually pupated during the test, thus vitiating the result.

Thus the *E. chrysogaster* larva, while relatively immune to attack by members of its own species, probably controls to some extent the output of *A. simpsoni* larvae from plant axils. Larvae of the latter species have never been found in axils inhabited by *E. chrysogaster*. Larvae of *Harpagomyia taeniarostris*, Theo., *Uranotaenia ornata* var. *musarum*, Edw., and *Culex* (*Culiciomyia*) *nebulosus*, Theo.—all common in plant axils in Bwamba—are also attacked and destroyed.

Females bite man freely in the forest, and sometimes in banana plantations, almost always attacking the legs below the knee. Males are quite common in the forest undergrowth.

(*b*) *E. semisimplicipes*, Edw.

Material studied consists of wild-caught larvae (confirmed by male dissection), reared larvae, reared pupae, and reared and wild-caught adults.

Larva.

The larvae cannot be distinguished with certainty from those of *E. chrysogaster*, but some guidance is given by the fact that the integument is usually white instead of brownish. The comb has usually fewer spines than that of *E. chrysogaster* (about 12-20) but a good deal of overlap occurs.

Pupa.

The tentative characters proposed by Edwards as perhaps distinguishing the pupae from those of *E. chrysogaster* have been found unreliable.

Adult.

Mainly as in Edwards' description, but the following points should be noted. The integument of the thorax does not appear much darker than that of *E. chrysogaster* in fresh specimens; but the scutal scaling is very dark, and this has been found a good field character in both sexes. The general colour of the scutum appears a soft pastel-black to the naked eye. Under the microscope the scaling is seen to be mainly black, with a powdering of yellow. The pluming of the male hind tarsi complies with Edwards' description and figure. Once again it has been found that the relative length of the male palps and proboscis is variable. In a series of 12 males reared from *Colocasia* axils, only 8 had palps definitely shorter than the proboscis. Even in specimens with short palps, Edwards' ratio of 3:4 is considered to be too low.

Field Notes.

Larvae are quite common in forest leaf-pools and in plant axils. They have the same habits as those of *E. chrysogaster* and are active predators as is shown by the following experiment:

> Four tubes were set up exactly as in the *E. chrysogaster* experiments, each with a large *E. semisimplicipes* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 7, 8, 9, 9 of the latter were devoured—a mean of about 8 per tube.

Females are frequently taken biting in the forest, and males are common in the forest undergrowth.

(*c*) *E. grahami*, Edw.

Material studied consists of wild-caught adults only.

Larva and Pupa.

None has so far been taken in Bwamba. It is pointed out that the form of the larval comb spines is not a reliable specific character (*see* under *E. chrysogaster*).

Adult.

Wild-caught males from forest undergrowth have been identified by the absence of tarsal plumes and by examination of the terminalia. None has had any trace of a pale line on the underside of the proboscis. Some females of the *E. chrysogaster* group, taken biting in forest, have been assigned to this species as they lacked the pale line, which is usually clearly visible in Bwamba specimens of *E. chrysogaster* and *E. semisimplicipes*.

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(*a*) *E. inornatus*, Newst.

The material studied includes numerous wild-caught specimens in all stages and a critical reared series comprising 23 larval skins, 8 whole larvae, 21 pupal pelts, 16 males, and 6 females. As the larva and pupa are now described for the first time, the series includes the paedotype.

Larva (fig. 3).

Length 9-12 mm.; *colour* whitish; *head* horn-colour; *siphon* dark brown. *Head* about as long as broad. Antennal tuft a single slender hair at about $\frac{2}{3}$. All head setae small and inconspicuous. Mentum broader than long, with about 5 teeth on either side of a rather small central tooth. Outermost teeth scarcely larger than the others. *Thorax* with the mesothoracic pleural group consisting of 2 long

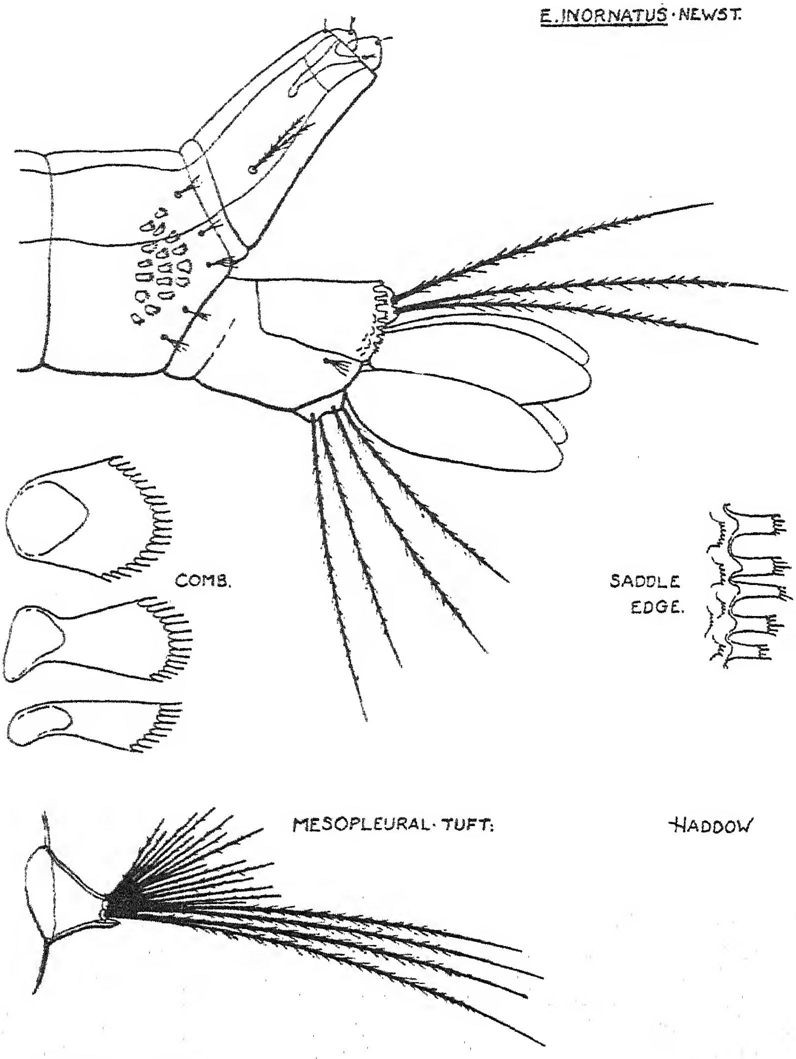

FIG. 3.—The larva of *Eretmapodites inornatus*, Newst. Drawn from a freshly killed specimen mounted in lactophenol without pressure.

subplumose setae (1 single and 1 double, or both double) and a much shorter seta with 12 to 24 stiff, needlelike branches, of which the longest are about $\frac{1}{2}$ the length of the long setae. Mesothoracic lateral hairs usually double, but sometimes single or 3-branched. *Abdomen* with the lateral setae of segments *I-III* borne on large smooth bosses, those of succeeding segments on smaller but quite distinct

bosses. On segment *I* usually 2 single setae arise from the boss, but 1 or both may be bifid. On segment *II* there are usually 3 single setae arising from the boss, but 1 of these may be bifid or even trifid. Perhaps the third is the main ventral seta, whose boss has become fused to that of the lateral setae proper. On succeeding segments there is a single lateral seta. Comb consisting of 5 to 20 (usually about 12) weakly sclerotised scales with pronounced terminal fringes, arranged in a patch or irregular double row. Tuft *B* of segment *VIII* weak and inconspicuous, with 5 to 6 branches. Siphon with index $1\frac{1}{2}$ to 2 in life, about 1 in specimens mounted with pressure. Conical in such specimens, but in life almost cylindrical and slightly curved. Pecten absent. Subventral tuft a rather stout subplumose seta at about $\frac{1}{3}$, usually double but sometimes single or triple, about as long as the diameter of the siphon at the point of attachment. Saddle small, incomplete, and lightly sclerotised, the posterior edge markedly crenellate and the crenellae bearing terminal fringes. Lateral seta small and weak, with 3 to 4 branches, arising below the edge of the saddle. Upper and lower caudal setae single or double, subplumose. Ventral brush consisting of 4 pairs of unbranched plumose setae (occasionally 1 may be bifid). Gills subequal, sausage shaped, about 2 to 3 times the length of the saddle.

Pupa (fig. 9).

Integument pale throughout, without markings. Trumpet of medium length, obliquely truncate, medium brown, paler at the base and tip. Dorsal seta rather stout. Float-hair with 3 to 8 rather stout, black, plumose branches, which are frequently subdivided distally into 2 or 3. *K* postero-lateral to *H*. *C-II* distinctly shorter than *B-II*. All the main setae black and not longer than the succeeding segments. *A-VII* with 4 to 12 and *A-VIII* with 8 to 18 strong, black, plumose branches, a few sometimes being subdivided. The longest branches of *A-VIII* reach well behind the distal extremities of the paddles. Paddles very small, pale yellow with slightly infuscate midrib, oblong-ovate, with pronounced marginal fringe. Distinctly shorter than *X* in the male. Seta enormous, with 6 to 15 black plumose branches, some of which are distinctly longer than the paddle.

Note.—The pupae of *E. inornatus* and *E. quinquevittatus* are thus strikingly similar. At the moment it seems doubtful whether they can be distinguished, except perhaps on small differences in the form of the paddles. The late Mr. E. G. Gibbins has recorded *E. quinquevittatus* from Bwamba (1942). His African assistant informs me that these specimens—from plant axils—were identified as pupae. They came from an area where the writer has taken *E. inornatus* in plant axils. During $2\frac{1}{2}$ years' work in Bwamba, *E. quinquevittatus* has not been found, and in any case it is thought that records of this species from Uganda should be accepted with reserve (Hopkins, private communication). There seems little doubt that Gibbins' record should be referred to *E. inornatus*.

Adult.

Male—as in Edwards' description, with a few minor differences. The post-spiracular hairs are yellowish in all Bwamba specimens. Silvery markings of the 7th abdominal tergite sometimes meeting to form a complete band. Proximal claspettes tipped by a single very fine hair. This hair would probably be invisible in balsam mounts, such as are recommended by Edwards. The sigmoid hairs at the tips of the distal claspettes have peculiar T-shaped terminations, visible only when the crossbar of the T lies parallel with the coverslip (fig. 7, D).

Female—as male. The foreclaws are slightly unequal. The longer bears a large tooth, the other a small but quite distinct tooth (fig. 5).

Field Notes.

Larvae have been found in snail shells (*Achatina* and *Limicolaria* spp.), in forest leaf-pools, and in *Colocasia* axils. They have a pronounced browsing habit. In life the peculiar multifid seta of the mesothoracic pleural group projects downward, outward and forward, making contact with the surface on which the larva is feeding. Development is slow. This species is less actively predatory than the members of the *E. chrysogaster* group, as is shown by the following experiment:

> Four tubes were set up exactly as in the *E. chrysogaster* experiments, each with a large *E. inornatus* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 2 *A. simpsoni* were devoured in each tube.

The habit of the pupa is peculiar, on account of its small paddles with their enormous setae and of the equally enormous fan-shaped setae of segments *VII* and *VIII*. At the surface the pupa hangs with the abdomen projecting backward and downward in almost a straight line—an attitude resembling that seen in other species just before emergence of the adult. When swimming, it does not progress by the usual crisp strokes of the flexed abdomen, but by a peculiar weak wriggling and shivering movement, the abdomen hardly being flexed unless the pupa is swimming straight downward. These habits are so characteristic that the pupae can be picked out in the field without a lens. It would be interesting to know whether the very similar pupa of *E. quinquevittatus* behaves similarly. Development usually lasts 3 to 4 days.

Females have been taken biting in quite large numbers in many parts of the forest, and males are common in the undergrowth.

(*b*) *E. penicillatus*, Edw.

The material studied includes wild-caught specimens in all stages and a critical reared series comprising 14 larval skins, 4 whole larvae, 14 pupal pelts, 11 males, and 3 females. As the larva and pupa have not previously been described, the foregoing series includes the paedotype. The female is now also described for the first time and the paedotype adult (a female) has been designated as the neallotype.

Larva (fig. 4).

Length 10 to 12 mm.; *colour* white; *head* horn-colour; *siphon* dark brown. *Head* a little broader than long. Antennal tuft a single delicate seta just beyond $\frac{1}{2}$. Head setae all delicate and inconspicuous. Mentum broader than long, with about 7 teeth on either side of a rather small central tooth, the outermost teeth being larger than the remainder. *Thorax* with the mesothoracic pleural group consisting of 2 long, single, subplumose setae and a much shorter seta which is divided into 3 to 8 stiff, needlelike branches. Mesothoracic lateral hairs single. *Abdomen* with the lateral setae of segments *I-III* borne on large smooth bosses, those of segments *IV* and *V* on small bosses. On succeeding segments bosses are extremely small or absent. On segment *I*, 2 single lateral setae arise from the boss, on segment *II*, 3 single lateral setae (*see* under *E. inornatus*). On succeeding segments there is a single lateral seta. Comb consisting of 8 to 15 weakly sclerotised scales, with pronounced terminal fringes, arranged in a patch or irregular single or double row. Rarely, as many as 20 scales may be present. Tuft *B* of segment *VIII* very minute and delicate, 2 to 4 branched. Siphon with index about $1\frac{1}{2}$ to 2 in life, about 1 in specimens mounted with pressure. Rather conical in such specimens, but in life almost cylindrical and slightly curved. Pecten absent. Subventral tuft a rather stout subplumose seta at about $\frac{1}{2}$ with 1 to 3 (usually 2) branches, about as long as the diameter of the siphon at the point of attachment. Saddle small, incomplete, and lightly sclerotised, the posterior edge crenellate and the crenellae fringed as in the case of the comb scales. Lateral seta minute, 3 to 4

branched, arising below the edge of the saddle. Upper caudal seta single or double, lower double. Caudal setae subplumose. Ventral brush consisting of 4 pairs of unbranched plumose setae. Gills subequal, sausage-shaped, about 2 to 3 times as long as the saddle.

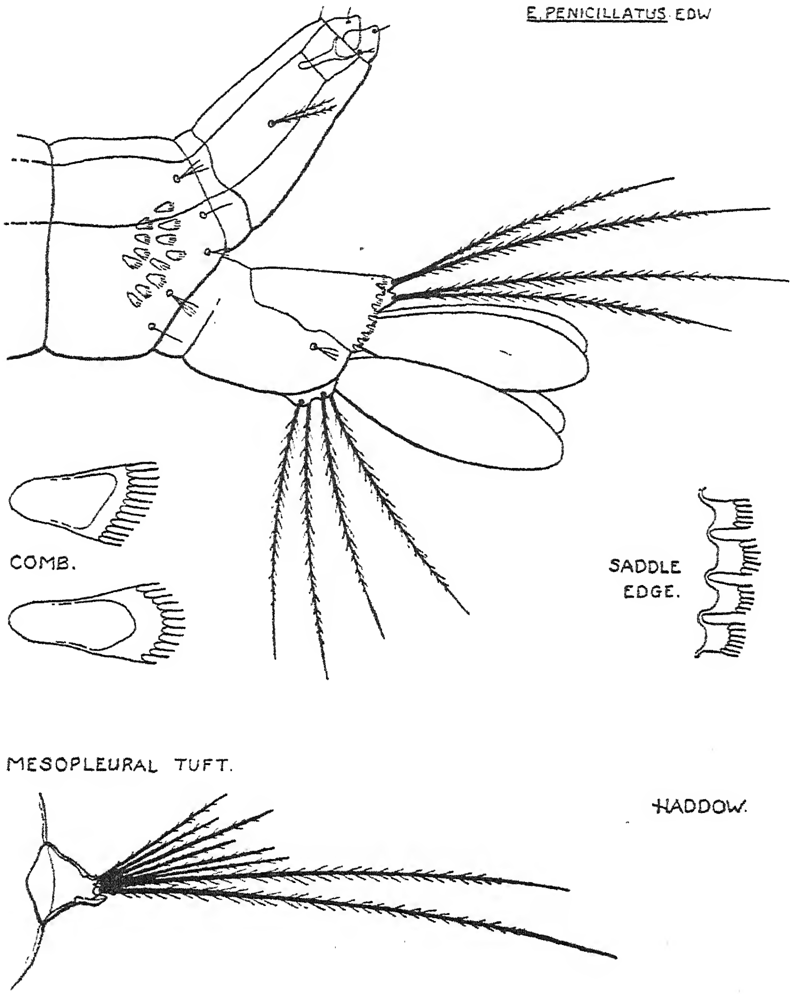

FIG. 4.—The larva of *Eretmapodites penicillatus*, Edw. Drawn from a freshly killed specimen mounted in lactophenol without pressure.

Pupa (fig. 9).

Integument pale yellow throughout, without markings. Trumpets long, obliquely truncate, medium brown, paler at the base and tip. Dorsal seta rather stout. Float-hair with 4 to 8 rather stout, black, weakly plumose branches. *K* postero-lateral to *H*. *C-II* distinctly shorter than *B-II*. All the main setae black and shorter than the succeeding segments. *A-VII* with 6 to 12 and *A-VIII* with 8 to 14 strong, black, plumose branches, a few of which may be subdivided. Paddles pale yellow with slightly infuscate midrib, oblong-ovate, with pronounced marginal fringe, and longer than *X* in the male. Seta with 4 to 8 black, plumose branches, less than ½ the length of the paddle.

Adult.

Male—almost as in Edwards' description, but the following points should be noted. The brown stripes on the scutum are usually lighter than those of *E. inornatus* (in life), but this character can only be used in the presence of comparative material. Almost all the pleural hairs are yellowish. Silvery markings on the 7th abdominal segment sometimes meet in the mid-line to form a complete band. In Edwards' description of the male terminalia he mentions a marked enlargement in the middle of the style, but states that a male from Freetown had a style almost without this enlargement. He also states that the distal claspettes have simple hairs at the tip, but his figure shows a sigmoid hair in this position. In Bwamba material, 2 types of male have been noted—one with enlargements midway on the styles and sigmoid hairs at the tips of the distal claspettes, the other without enlargements, and with simple hairs only. As both types have identical larvae and pupae it does not seem advisable to subdivide the species, and the writer regards these 2 types as lying at the extremes of individual variation. It should be noted that though the proximal claspettes are very large, they are extremely transparent and easily damaged. They are always difficult to see in mounts, particularly if they overlie other structures. The terminal hairs of the proximal claspettes are not merely enlarged at the tips but have quite pronounced marginal fringes (fig. 7, G).

Female—as male. In one specimen the silvery markings of the 2nd abdominal tergite lie for the most part along the margin of the sclerite. The claws of the foreleg are slightly unequal. The longer bears a large tooth. The other is without a tooth in most cases, but sometimes bears a very minute bristlelike tooth-rudiment (fig. 5, and *see E. inornatus*).

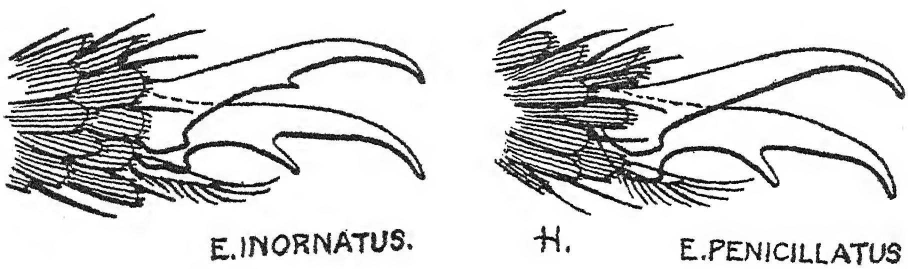

FIG. 5.—The fore claws of female *Eretmapodites inornatus*, Newst., and *E. penicillatus*, Edw.

Note.—Edwards has suggested that *E. penicillatus* may be conspecific with *E. melanopus*, Graham, of which the type male is no longer in existence. It is possible that information on this subject might be gained by comparing the fore-claws of the Bwamba females with those of the existing females of *E. melanopus*. If these should prove identical, then the position must remain as before, but a definite difference would finally establish *E. penicillatus* as a separate species. In the event of conspecificity all specimens of *E. penicillatus* would, of course, have to be referred to *E. melanopus*.

Field Notes.

So far all larvae have been found in dark-brown water in snail shells (*Achatina* and *Limicolaria* spp.) in the forest. They have the usual browsing habit, and in life the multifid seta of the mesothoracic pleural group assumes the same position as in *E. inornatus*, q.v. In nature larvae sometimes support a very heavy growth of stalked ciliates, of the *Vorticella* and *Carchesium* types, and in such cases the pupa almost always dies just after the last larval moult. Development is slow,

even when food is abundant. Though many may be found together in one shell, larvae of other genera are never found in their company, on account of the marked predatory habit which is demonstrated in the following experiment:

Four tubes were set up exactly as in the *E. chrysogaster* experiments, each with a large *E. penicillatus* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 3, 5, 5, 8 *A. simpsoni* larvae were devoured respectively, a mean of about 5 per tube.

The pupae are markedly pale till just before emergence of the adult, when rapid darkening occurs, the scutal pattern becoming clearly visible through the thin integument.

A few females have been taken biting within the forest edge, and males are quite common in the undergrowth.

3. The *E. quinquevittatus* group.

Only 1 member of this group has been found in Bwamba. Previous workers in this area (J. O. Harper, private communication, and E. G. Gibbins, 1942) referred their material to *E. dracaenae,* Edw., as did the writer, till examination of the male terminalia showed that this is a new species. Apart from the terminalia, this species closely resembles the description of *E. dracaenae.* It is here described under the name of *E. ferox,* sp. n., the name having been given on account of the savage nature of the larva.

(*a*) *E. ferox,* **sp. n.**

The material studied consists of abundant wild-caught specimens in all stages, and a critical reared series (including the male and female types) comprising 15 larval skins, 15 pupal pelts, 6 males, and 9 females.

Larva (fig. 6).

Note.—Though the larva closely resembles Hopkins' description of that of *E. dracaenae,* it seems advisable to give here a full description, as Hopkins' material consisted of a single damaged larva, whose siphon had probably been subjected to pressure.

Length about 10 to 12 mm.; *colour* whitish; *head* brown; *siphon* almost black. *Head* about as long as broad. Antennal tuft a single slender seta at about $\frac{2}{3}$. All head setae small and inconspicuous. Mentum broader than long, with about 7 to 9 teeth on either side of a slightly larger central tooth. Outer teeth larger than the others. *Thorax* with the mesothoracic pleural group consisting of 2 long double or single subplumose setae and a shorter seta which may be single or double. Lateral hairs single or double. *Abdomen* with the lateral setae of segments *I-III* sometimes arising from tiny smooth bosses, but these are usually absent. Lateral setae of other segments without bosses. On segments *I* and *II* the lateral setae are 2 in number, 1 single and 1 double, as usual. On segment *III* there is 1 lateral seta, which is usually double. Comb consisting of 7 to 20 (usually 8 to 10) strong spines, arranged in an irregular single or double row. The spines have a strong central tooth and numerous small secondary denticles on either side. They are extremely varied in shape, but often present the tridentate appearance described by Hopkins in the case of *E. dracaenae.* Tuft *B* of segment *VIII* rather prominent, black, subplumose, with 3 to 5 branches, some of which may be subdivided, as in fig. 6. Siphon with index about 2 to $2\frac{1}{2}$ in life and about $1\frac{1}{2}$ in specimens mounted with pressure. Rather conical in such specimens, but in life slightly biconvex. Pecten composed of 4 to 6 (usually 4) strong, prominent spines. These are often completely simple, but may bear 1 or 2 secondary denticles. Subventral tuft a fairly stout black subplumose hair at about $\frac{1}{2}$, usually double, shorter than the

diameter of the siphon at the point of attachment. Saddle small, incomplete, and lightly sclerotised, with crenellate postero-ventral margin. The crenellae are fairly well marked and bear apical fringes. Lateral seta small and inconspicuous, with about 4 branches, arising below the edge of the saddle. Upper and lower caudal setae usually double, subplumose. Ventral brush composed of 4 pairs of subplumose setae, of which 1 or 2 are often double. Gills 2 to 3 times the length of the saddle, somewhat leaf-shaped and bluntly pointed as in *E. leucopus* subsp. *productus*, Edw.

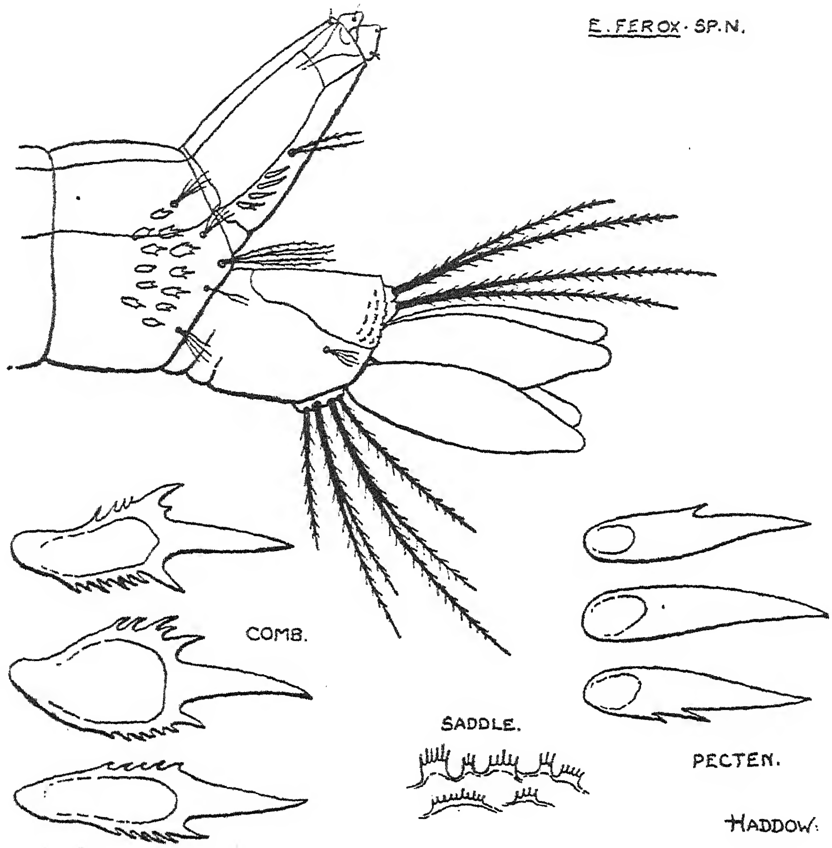

FIG. 6.—The larva of *Eretmapodites ferox*, sp. n. Drawn from a freshly killed specimen mounted in lactophenol without pressure.

Pupa (fig. 9).

Similar to Edwards' description of the pupa of *E. dracaenae*, but with some small, perhaps inconstant difference. The main features are: integument pale-brown, shagreened; *B-II* often longer than, and *B-III* about equal to, the succeeding segment; *A-VII* with 2 to 6 (usually 4) and *A-VIII* with 4 to 9 (usually 6) stout black plumose branches; *X* a little shorter than the paddles in the male; paddles rather short and broad, squarish, with a single short seta, less than $\frac{1}{2}$ the length of the paddle. The paddle seta is often (but not always) angled about the middle.

Adult.

Male.—As in Edwards' description of *E. dracaenae* (apart from the terminalia), but a few points should be noted. The scutal markings are rather variable (as also in *E. oedipodius* subsp. *parvipluma*, Edw., and *E. leucopus* subsp. *productus*, Edw.). The extension forward of yellow lines, etc., used by Edwards as a

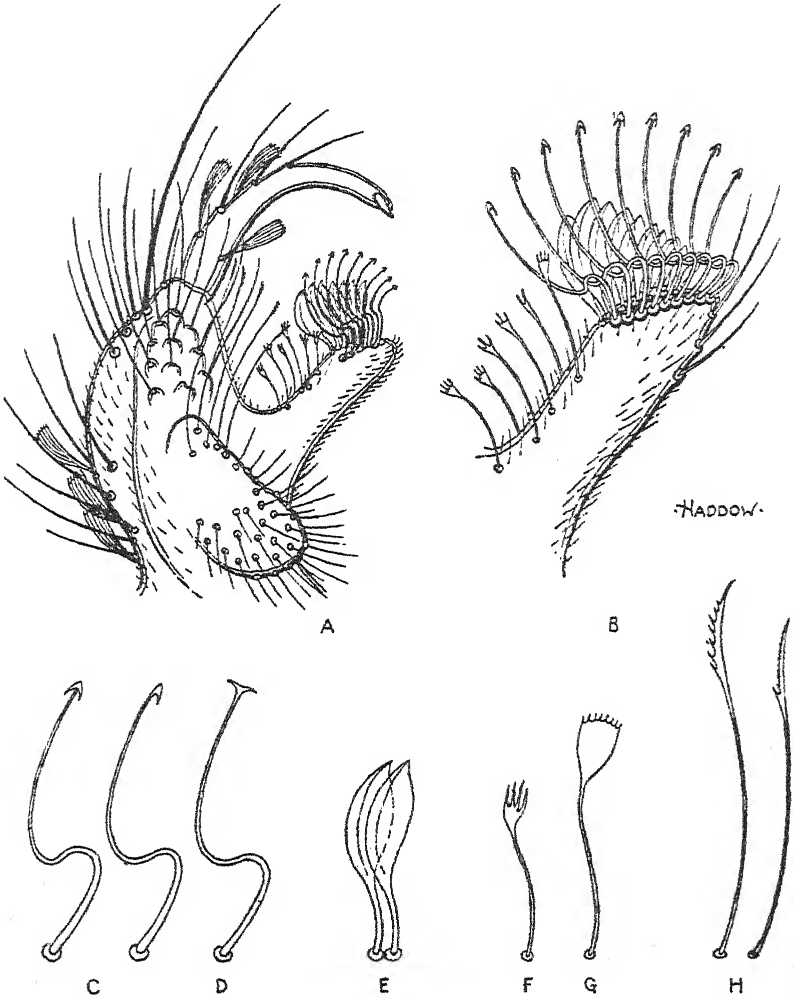

FIG. 7.—*Eretmapodites ferox*, sp. n., male terminalia: A.—Tergal view of coxite; B.—Basal lobe as seen in a freshly killed unmacerated specimen mounted in lactophenol without pressure; C.—Sigmoid hairs from basal lobe; D.—Sigmoid hairs from distal claspette of *E. inornatus* for comparison; E. spoon-shaped scales from basal lobe; F.—Digitate hair from basal lobe; G.—Hair from proximal claspette of *E. penicillatus* for comparison; H.—Serrate hairs from distal claspette.

diagnostic character in this group, is not considered to be reliable. On abdominal tergite I there are silvery marks laterally (but not dorsally, as in Edwards' description of *E. quinquevittatus*, Theo.). Tergites 6 and 7 with complete dorsal silvery bands. All the abdominal silvery markings with a distinct pink or purplish sheen. Legs mainly black, but with bronzy reflections. All femora extensively

yellow on the ventral side and toward the base dorsally. The hind femur has a distinct white knee-spot, and the middle femur has usually a similar but much smaller spot. In pale specimens the front and middle tibiae may be yellowish ventrally almost throughout their length, while in dark specimens they may be almost entirely black. The hind tibiae have a stripe of pale scales on the middle third ventrally. The tarsi often show a certain amount of pale scaling ventrally. *Terminalia* (fig. 7)—Coxite rather short and broad, bearing a conspicuously long hair on the outer margin as in *E. dracaenae*. No scale tuft on the inner sternal aspect. Apical lobe not clearly differentiated, bearing numerous long simple hairs. Basal lobe, long and prominent, bearing a remarkable assortment of modified hairs and scales. From some (tergal) angles it appears as a long arm, obliquely truncate at the tip as in *E. quinquevittatus*, while from others it may appear almost as short as in Edwards' figure of *E. dracaenae*. The basal portion bears a number of rather short hairs, not unlike the " battledore " hairs of the *E. inornatus* group (but with smaller terminal expansions) which are so deeply divided as to appear almost digitate (fig. 7, F). Terminally there is a row of about 10 large sigmoid hairs with peculiar harpoon-shaped tips, which from some angles appear merely hooked (fig. 7, C). Beside these is a row of scales, which are not leaf-shaped, but spoon-shaped, each fitting into the hollow of the next. Distal claspettes covered proximally with numerous rather short simple hairs. Distally they bear a few long hairs with serrated tips (fig. 7, H) as in Edwards' figure of *E. dracaenae*. Proximal claspettes absent. Style rather strongly curved and evenly tapering, with a fair number of hairs and scales.

Female—as above. The 4th abdominal sternite usually bears a dark apical band in the male (as do sternites 5, 6 and 7), but in the female this is usually absent and the band on sternite 5 is small.

Field Notes.

The larva occurs most frequently in plant axils, particularly those of *Colocasia* and *Dracaena ugandensis*, but it has also been found in leaf-pools in forest and banana plantations. It is perhaps the most actively predatory mosquito larva known to the writer and the only one which sometimes goes in pursuit of its prey. If an *A. simpsoni* larva is placed in a small dish with a large *E. ferox* larva, the latter will in many cases cross the dish straight to its prey, swimming by means of its mouth-brushes (a peculiar, rapid, gliding motion) and, seizing it immediately, will begin to shake and worry it much as a dog shakes a rat. The savage nature of this larva is shown by the fact that it almost always occurs alone in an axil. Where 2 occur together they are always of the same size, and field observation shows that they constantly attack each other. Under the microscope members of such a pair will be found to have all the main body setae cropped off short and the gills of both will show considerable damage. An experiment to demonstrate the predatory habit was carried out as follows:

Four tubes were set up exactly as in the case of the *E. chrysogaster* experiments, each with a large *E. ferox* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 8, 9, 9 and 10 *A. simpsoni* were devoured—a mean of 9 per tube. Thus after 24 hours there were only 4 survivors of the original 40 *A. simpsoni*. In 1 tube 5 larvae had been consumed in the first hour and 2 more killed. In this tube all ten larvae had been consumed within 6 hours. The *E. ferox* larva does not always consume a victim completely before attacking the next, and in an experiment like the foregoing the tubes are soon littered with dead and dying larvae and unconsumed fragments.

Females bite man freely within the forest edges and to a less extent in banana plantations, usually attacking the legs below the knee. In the past 2½ years about 1,700 have been taken biting. Males are common in the forest undergrowth.

4. The *E. oedipodius* group.

Only 1 member of this group—*E. leucopus* subsp. *productus*, Edw.—is common in Bwamba. *E. oedipodius* subsp. *parvipluma*, Edw., also occurs, but is very rare. As larvae of these 2 species are almost indistinguishable, records are confined to such as have been reared out in the laboratory.

(*a*) *E. oedipodius* subsp. *parvipluma*, Edw.

Material studied consists of a few wild-caught larvae reared out in the laboratory, and a small number of wild-caught males and females.

Larva, Pupa, and Adult.

Mainly as described by Hopkins and Edwards. In the case of the larva it is thought that Hansford's figure (in Hopkins) is somewhat misleading. It was probably made from a specimen mounted with pressure. Local specimens are almost indistinguishable from the larva of *E. leucopus* subsp. *productus* (fig. 8) and the pupae also show close similarity (fig. 9). Such small differences as have been noted probably lie within the range of individual variation. It should be noted that Hopkins' description applies to the subsp. *parvipluma*, Edw. (*See* Edwards, 1941, " Corrigenda & Addenda ".)

Field Notes.

All the Bwamba larvae have been taken in leaf-pools in the forest, sometimes in company with those of other *Eretmapodites*. No tests on predatory activity have been carried out, as it was not possible to tell which larvae were *oedipodius* till the adults had emerged.

A few males have been found in forest undergrowth, and 1 or 2 females have been taken biting.

(*b*) *E. leucopus* subsp. *productus*, Edw.

Material studied includes abundant wild-caught specimens in all stages and a critical reared series (which includes the subspecific paedotype) comprising 14 larval skins and 3 whole larvae, 8 pupal pelts, and 10 adults.

Larva (fig. 8).

Bwamba larvae comply closely with Hopkins' description of that of *E. oedipodius* subsp. *parvipluma*, but a few minor points and individual variations may be worth noting. The chitinous plaques or bosses on the abdominal segments, though perfectly smooth and weakly sclerotised, are quite large and easily seen. The double hair of the lateral group in the first 2 abdominal segments may have an extra branch—even 4 to 6 in exceptional specimens. The comb has 5 to 9 (usually 6) strong spines arranged in an irregular row. Tuft *B* of segment *VIII* may have as many as 5 branches, though 3 is the usual number. The siphon in life is biconvex, extremely dark, and with an index of $2\frac{1}{2}$ to 3. In specimens mounted with pressure it is rather conical, with an index of about 2. The pecten consists of 3 to 7 (usually 5) strong spines with a powerful central tooth and several small secondary denticles on one or both sides. In local specimens the lateral hair arises below the edge of the saddle. Some of the setae of the ventral brush may be double. The gills are subequal, about 3 times as long as the saddle,

somewhat leaf-shaped and bluntly pointed. A figure has been given, as local specimens of *E. l. productus* and local and Entebbe specimens of *E. o. parvipluma* differ from Hansford's figure in the form of the gills, siphon, saddle, and pecten-spines.

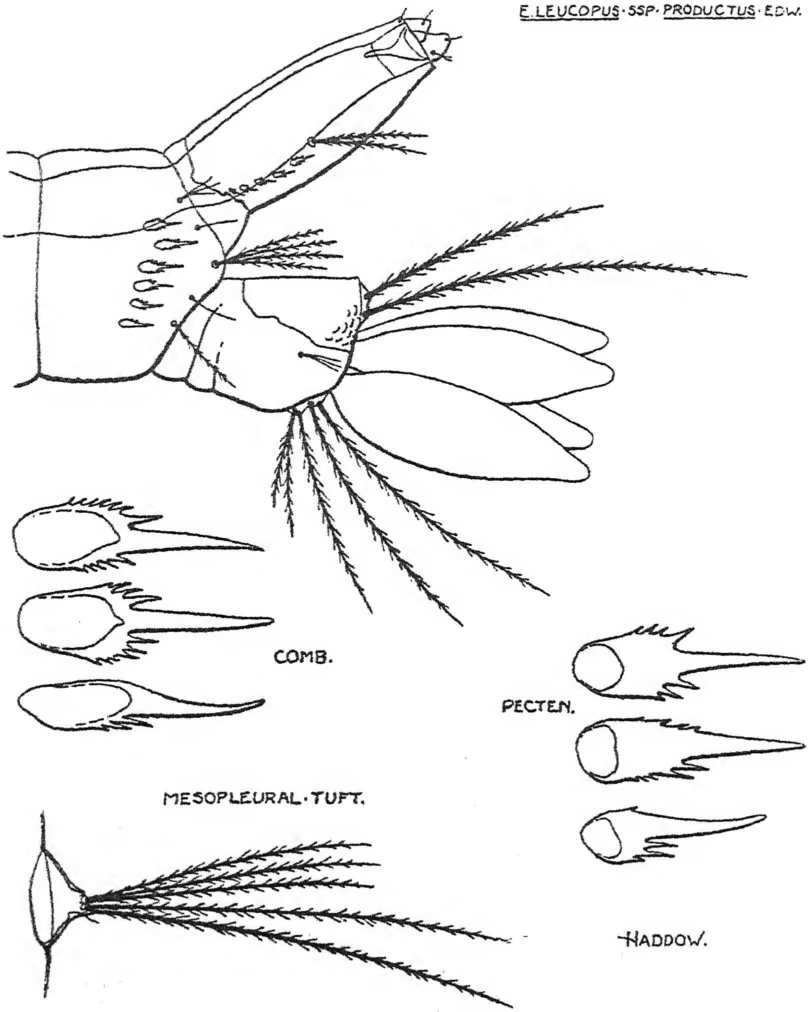

FIG. 8.—Larvae of *Eretmapodites leucopus* subsp. *productus*, Edw. Drawn from a freshly killed specimen mounted in lactophenol without pressure.

Pupa (fig. 9).

Local specimens comply closely with Edwards' descriptions of *E. oedipodius*, Graham, and *E. leucopus*, Graham. A possible difference exists in the form of the paddles. Edwards describes those of *E. oedipodius* as " truncate but not emarginate apically " but unfortunately gives no figure. The paddles of *E. l. productus* are not truncate but distinctly rounded apically. This distinction may not hold good, as the paddles of local and Entebbe specimens of *E. o. parvipluma* are also rounded rather than truncate.

Adult.

Local material complies with Edwards' description for the most part, but occasionally a very dark phase occurs in which the scutal pattern resembles that found in the *E. inornatus* group. In such specimens the male terminalia are exactly the same as in normally coloured individuals. Intermediate forms have not so far been seen. It is interesting to note that similar dark forms have been found in Kenya by Dr. P. C. C. Garnham, and are at present under study (private communication).

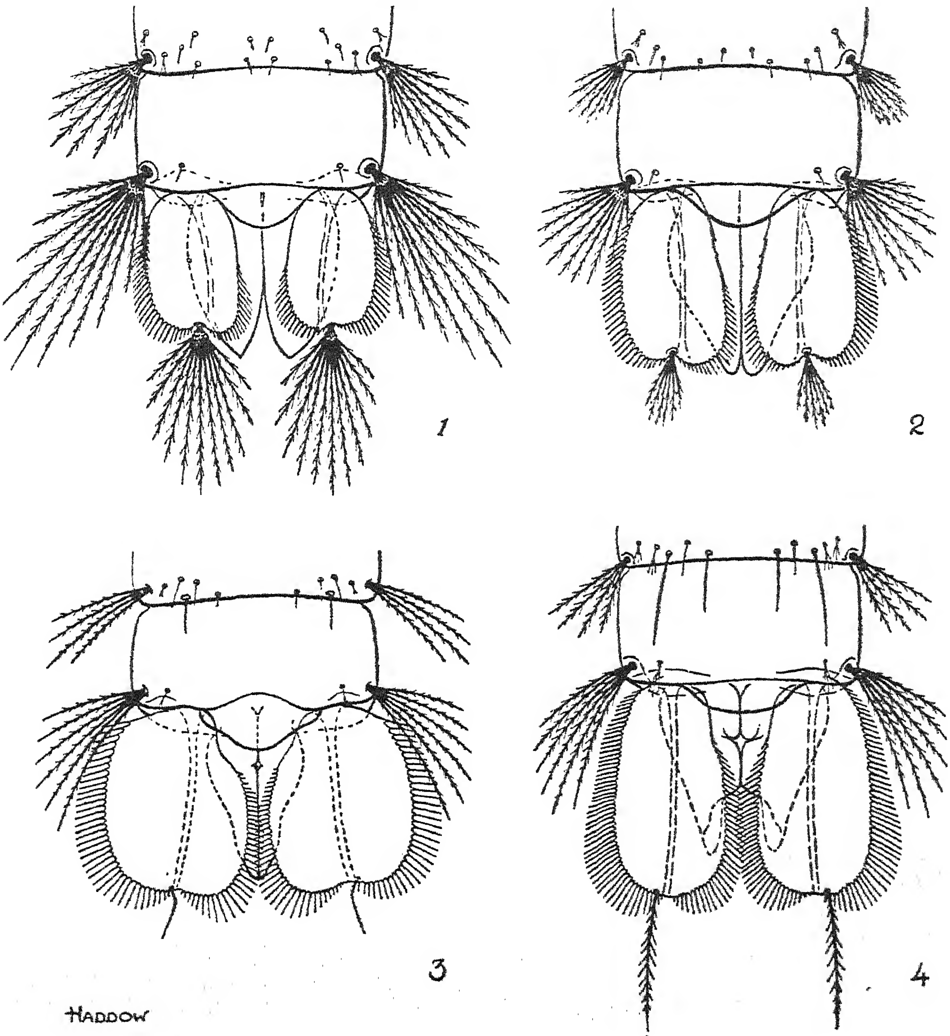

FIG. 9.—Pupal paddles of: 1, *Eretmapodites inornatus*, Newst. 2, *E. penicillatus*, Edw. 3, *E. ferox*, sp. n. 4, *E. leucopus* subsp. *productus*, Edw.

Field Notes.

Larvae are quite abundant in plant axils and in forest leaf-pools. They have occasionally been taken in tree-holes containing dark water with dead leaves. They are more prevalent in the axils of low plants such as pineapple and *Colocasia*

than in the higher types such as bananas. The larvae have a characteristic dead-white appearance and this, combined with the rather long and very dark siphon, enables them to be picked out quickly in the field. The food in the gut is always of a very dark greenish-black colour, while other species occurring in the same foci usually have light-brown gut contents. The larva has a very characteristic habit which might be described as "sounding"—when leaving the surface it swims straight down to the bottom using the mouth-brushes only. It is an active browser, progressing rapidly along the bottom in a sinuous line, browsing with a slight sweeping movement of the head to either side. The larvae are only mildly predatory, as is shown by the following experiment:

> Four tubes were set up exactly as in the *E. chrysogaster* experiments, each with a large *E. l. productus* larva and 10 medium-sized *A. simpsoni* larvae. In 24 hours 1, 2, 2, 2 *A. simpsoni* larvae were devoured—a mean of less than 2 per tube.

Adults are widespread in Bwamba in the forest and in banana plantations. Females are rarely taken in large numbers, but a few have been present in almost every catch made in the forest.

Keys.

It has been necessary to prepare keys to include the new material and to delete characters thought to be unreliable. The keys follow as far as possible those given by Hopkins and Edwards, but the deletion of doubtful characters has led to the grouping of certain species formerly regarded as distinguishable on external appearance. As much of the material discussed in the present paper has not yet been compared with the collections in the British Museum, it seems better to resort to such grouping than to differentiate species on grounds which later work may prove to be unsound.

In using the larval key it should be remembered that the lateral setae of abdominal segments *I* and *II* are very variable. Further, certain species are known at present from very scanty material, and in such the range of individual variation cannot be gauged; for example, when further material of *E. argyrurus* is described it may be found that larvae of this species are not distinguishable from those of *E. penicillatus*. Hopkins' use of siphonal indices has not been followed, as the siphons of all the local larvae, though apparently strong, are easily distorted by the least pressure of the coverslip. If the siphonal index of *E. dracaenae* should really be only about 1, then it will be easy to distinguish larvae of this species from those of *E. ferox*, where the siphonal index is about 2.

In constructing the pupal key, only readily visible characters have been used. Such features as the length-width ratios of the trumpets are easily altered by coverslip pressure and are in any case difficult to estimate. Edwards' tentative differentiation of the pupae of *E. chrysogaster* and *E. semisimplicipes*, based on the length and colour of certain abdominal setae, has proved unsound. As his differentiation of other members of the *E. chrysogaster* group is based on the same character, it seems likely that it will be found unreliable also. Accordingly, all the pupae of this group have been placed together as indistinguishable.

In the case of the key to adult females, the deletion of doubtful diagnostic characters has led to grouping of many species, particularly in the *E. inornatus* group. In the case of males, a key has been prepared which includes details of terminalia in cases where no reliable external diagnostic character is known to exist. It is seldom possible to determine a male finally without examining the terminalia and, using Edwards' book, the writer has found himself constantly referring back and forth from the key to the descriptions of terminalia. Among external adult characters discarded as unreliable are the thoracic pattern within the *E. quinquevittatus* group, the relative lengths of the male palpi and proboscis in the *E. chrysogaster* group, and the extent of the abdominal silvery scaling in the *E. quinquevittatus* and *E. inornatus* groups.

Key to the known *Eretmapodites* Larvae.

1. Lateral seta of abdominal segments *I-VI* arising from large conical sclerotised tubercles or bosses, the surface of which is denticulate......*chrysogaster*, Graham
intermedius, Edw.
subsimplicipes, Edw.
semisimplicipes, Edw.
grahami, Edw.

Lateral setae not arising from bosses, or from bosses the surface of which is smooth.. 2

2. Elements of comb strongly sclerotised spines.. 3
Elements of comb weakly sclerotised scales.. 5

3. Abdominal segments *I* and *II* (like segments *III-VI*) with only one strongly-developed lateral seta (forked at the base) on either side (? always) ....
silvestris, Ingr. & De M.

Abdominal segments *I* and *II*, with at least two separate strong lateral setae, either or both of which may be forked or single.................................. 4

4. Lateral setae of abdominal segments *I-VI* arising from large smooth bosses; comb of 2-8 (usually 6) spines.............. *oedipodius* subsp. *parvipluma*, Edw.
leucopus, Graham
leucopus subsp. *productus*, Edw.

Lateral setae not arising from bosses, or from very minute and rudimentary bosses; comb of 7-20 (usually 8-10) spines.......................*dracaenae*, Edw.
ferox, sp.n.

5. Tuft *B* of abdominal segment *VIII*, a very strong and conspicuous multifid seta...
quinquevittatus, Theo.

Tuft *B* of abdominal segment *VIII* weak and inconspicuous....................... 6

6. Short seta of the mesothoracic pleural group divided into 12-24 branches.........
inornatus, Newst.

Short seta of the mesothoracic pleural group divided into 3-9 branches......... 7

7. Comb of 8-20 (usually about 15) scales; pecten absent........*penicillatus*, Edw.
Comb of about 25 scales (? always); pecten sometimes present ...*argyrurus*, Edw.

Key to the known *Eretmapodites* Pupae.

1. Float-hair with 4-10 branches.. 2
Float hair single, or at most distally split into 2-3 branches....................... 6

2. Paddle-hair enormous, fanlike, with 10-17 branches..............*inornatus*, Newst.
quinquevittatus, Theo.

Paddle-hair relatively small, either single or with not more than eight branches 3

3. Paddle-hair single.. 4
Paddle-hair branched... 5

4. Trumpet narrowed just before the tip; opening almost transverse ....
oedipodius subsp. *stanleyi*, Edw.
oedipodius subsp. *parvipluma*, Edw.
leucopus, Graham
leucopus subsp. *productus*, Edw.

Trumpet not narrowed just before the tip; opening oblique ....
chrysogaster, Graham
intermedius, Edw.
subsimplicipes, Edw.
semisimplicipes, Edw.
grahami, Edw.

5. Paddle-hair with 2-4 (usually 2) branches, *A-VII* and *A-VIII* with 2-7 branches some *oedipodius* subsp. *stanleyi*, Edw.
some *oedipodius* subsp. *parvipluma*, Edw.
Paddle-hair with 4-8 branches, *A-VII* with 6-12 and *A-VIII* with 8-14 branches *penicillatus*, Edw.
6. Paddle-hair with 3-7 branches..*argyrurus*, Edw.
Paddle-hair single 7
7. Paddle-hair longer than the paddle.......................*silvestris*, Ingr. & De M.
Paddle-hair not more than ½ the length of the paddle..............*dracaenae*, Edw.
ferox, sp.n.

Key to the known *Eretmapodites* Females.

1. *apn* clothed with broad silvery scales.. 2
apn clothed with narrow yellow scales...13
2. Scutum without ornamentation, the yellow and black scales evenly mixed throughout 3
Scutum with some form of ornamentation, the yellow scales forming a border, a median line (perhaps faint and incomplete), or a pattern of stripes...... 6
3. Proboscis all dark...*grahami*, Edw.
Proboscis with a pale or white line beneath.. 4
4. Dark species, the scutum appearing almost black to the naked eye.............. *semisimplicipes*, Edw.
Lighter species, the scutum appearing not darker than medium brown to the naked eye 5
5. A distinct spot of silvery scales above the mid coxa...........*chrysogaster*, Graham
intermedius, Edw.
This marking absent or reduced to a patch of not more than 5 scales.............. *subsimplicipes*, Edw.
6. Scutum with the only ornamentation a more or less distinct yellow border...... 7
Scutum with at least traces of a median yellow band, or with a pattern of light and dark stripes.. 8
7. Hind tibiae normal, the scales at the tip decumbent...some *chrysogaster*, Graham
Hind tibiae enlarged at the tip, with prominent scales forming a tuft........... *silvestris* subsp. *conchobius*, Edw.
8. Scutum with ornamentation a median yellow line (sometimes faint and incomplete) 9
Scutum with the ornamentation a pattern of light and dark stripes............11
9. Hind tibiae normal; median band faint and short, confined to the area just anterior to the scutellum............................some *chrysogaster*, Graham
Hind tibiae enlarged at the tip, with prominent scales forming a tuft.........10
10. Scutum with a complete yellow median line...........*silvestris*, Ingr. & De M.
Scutum with a short median line anterior to the scutellum and a median line extending back a short distance from the anterior scutal margin.............. some *silvestris* subsp. *conchobius*, Edw.
11. Yellow stripes narrow (general appearance of scutum dark with a pattern of yellow lines) ....*inornatus*, Newst.
melanopus, Graham
forcipulatus, Edw.
penicillatus, Edw.
argyrurus, Edw.
Yellow stripes much broader (general appearance of scutum yellow with a pattern of dark stripes)...12

12. 7th abdominal tergite and at least the 6th and 7th sternites with a distal fringe of prominent black scales, which project to form a prominent ruff..............
dracaenae, Edw.
ferox, sp.n.

7th abdominal tergite with the black scales more or less appressed, not forming a conspicuous ruff..*quinquevittatus*, Theo.

13. Scutum with a pattern of narrow yellow lines as in the *E. inornatus* group; hind tarsi with white tips.. ....some *leucopus* subsp. *productus*, Edw.
Scutum with a pattern of much broader yellow lines as in the *E. quinquevittatus* group; hind tarsi dark or with white tips......................................14

14. Hind tarsi entirely dark..*oedipodius*, Graham
oedipodius subsp. *stanleyi*, Edw.
oedipodius subsp. *parvipluma*, Edw.
Hind tarsi with white tips...15

15. Third hind tarsal segment all dark..................................*leucopus*, Graham
leucopus subsp. *productus*, Edw.
Third hind tarsal segment with the tip white......................*plioleucus*, Edw.
plioleucus subsp. *brevis*, Edw.

Key to the known *Eretmapodites* Males.

1. *apn* clothed with broad silvery scales.. 2
apn clothed with narrow yellow scales..19

2. Scutum without ornamentation, the yellow and black scales evenly mixed throughout 3
Scutum with some form of ornamentation, the yellow scales forming a border, a median line (perhaps faint and incomplete), or a pattern of stripes...... 7

3. Proboscis all dark; hind tarsi simple..................................*grahami*, Edw.
Proboscis with a pale or white line beneath; hind tarsi with the last 2 segments more or less feathered with outstanding scales................................ 4

4. Dark species, the scutum appearing almost black to the naked eye; feathering of tarsi relatively slight.................................... *semisimplicipes*, Edw.
Lighter species, the scutum appearing light or medium brown to the naked eye 5

5. Tarsal feathering relatively slight; either no silvery scales above the mid coxa, or these scales forming a small patch of not more than 5 scales ....
subsimplicipes, Edw.
Tarsal feathering pronounced; a distinct patch of silvery scales above the mid coxa 6

6. Proximal claspettes with only a few hairs at the tip; distal claspettes with a patch of hairs at the tip..*chrysogaster*, Graham
Proximal and distal claspettes hairy over most of their surface...*intermedius*, Edw.

7. Scutum with the only ornamentation a yellow border.............................. 8
Scutum with at least traces of a median yellow band, or with a pattern of light and dark stripes.. 9

8. Hind tibia simple; hind tarsi with conspicuous feathering ....
some *chrysogaster*, Graham
Hind tibia enlarged at tip, with prominent scales forming a tuft; hind tarsi simple .... *silvestris* subsp. *conchobius*, Edw.

9. Scutum with ornamentation a complete or incomplete median line (perhaps faint and indistinct) 10
Scutum with ornamentation a distinct pattern of light and dark stripes.........12

10. Hind tibiae simple; hind tarsi conspicuously feathered; median line faint and short, restricted to the area just anterior to the scutellum......................
some *chrysogaster*, Graham
Hind tibiae enlarged at tip, with prominent scales forming a tuft; hind tarsi simple 11

11. Scutum with a complete median line.................... *silvestris*, Ingr. & De M.
Scutum with a short median line anterior to the scutellum, and a median line extending back a short distance from the anterior scutal margin..............
some *silvestris* subsp. *conchobius*, Edw.

12. Yellow stripes narrow (general appearance of scutum dark with a yellow pattern of yellow lines)...13
Yellow stripes much broader (general appearance of scutum yellow with a pattern of dark stripes)..17

13. A large tuft of projecting scales present on the inner sternal aspect of the coxite 14
This tuft absent, or represented by a very few scales which do not form a definite tuft 15

14. Basal lobe of coxite with prominent rows of large scales; proximal claspettes large but of simple form, bearing hairs with enlarged spatulate tips...........
argyrurus, Edw.
Basal lobe of coxite not so; proximal claspettes large and of peculiar shape, bearing numerous disciferous hairs...................................*tonsus*, Edw.

15. Distal claspette bent almost at right angles in the middle.........*forcipulatus*, Edw.
Distal claspettes not markedly angled in the middle...............................16

16. Proximal claspettes small and pointed, with at most a single hair at the tip......
inornatus, Edw.
Proximal claspettes very large, bearing numerous disciferous hairs
penicillatus, Edw.

17. 7th abdominal tergite with the black scales more or less appressed, not forming a prominent ruff; coxite with a conspicuous scale-tuft on the inner sternal face .... *quinquevittatus*, Theo.
7th abdominal tergite (and at least the 6th and 7th sternites) with a fringe of prominent black scales forming a distinct ruff; coxite without a scale-tuft...18

18. Basal lobes without sigmoid hairs; short hairs of the distal claspettes with enlarged tips...*dracaenae*, Edw.
Basal lobes with a terminal row of sigmoid hairs with harpoon-shaped tips; short hairs of the distal claspettes simple...............................*ferox*, sp.n.

19. Scutum with a pattern of narrow yellow lines as in the *E. inornatus* group; hind tarsi with white tips.......................... some *leucopus* subsp. *productus*, Edw.
Scutum with a pattern of much broader yellow stripes as in the *E. quinquevittatus* group; hind tarsi all dark or with white tips......................................20

20. Hind tarsi entirely dark; the last 2 segments feathered and angled............21
Hind tarsi with white tips; the last 2 segments simple..........................24

21. One claw of middle tarsi broad and bladelike; tarsal feathering pronounced...22
Both claws of middle tarsi slender as usual; tarsal feathering slight and not very conspicuous 23

22. 5th mid-tarsal segment shorter than 4th; tip of distal claspettes with about 10 reflexed hairs; basal lobe of coxite without scales.........*oedipodius*, Graham
5th mid-tarsal segment as long as 4th; tip of distal claspettes with about 15 reflexed hairs; basal lobe of coxite with a few, narrow, pointed scales......... *oedipodius* subsp. *stanleyi*, Edw.

23. Reflexed hairs of distal claspettes in a regular series; proximal claspette with a broad, axe-shaped terminal leaf............*oedipodius* subsp. *parvipluma* Edw.
Reflexed hairs of distal claspette crowded at the tip; proximal claspettes with a narrow, pointed terminal leaf.............. *oedipodius* subsp. *wansoni*, Edw.

24. 3rd hind tarsal segment all dark..25
3rd hind tarsal segment white at the tip..26

25. Distal claspette shorter than proximal claspette and bearing a few simple hairs at the tip..*leucopus*, Graham
Distal claspette longer than proximal claspette and bearing 2 long, flattened, sigmoid setae at the tip.......................*leucopus* subsp. *productus*, Edw.

26. Coxite with a small external projection; basal lobe with 3 very long and slender scales and some hairs at the tip....................................*plioleucus*, Edw.
Coxite without an external projection; basal lobe with 3 scales, 1 much broader than the others, at the tip, and without hairs...*plioleucus* subsp. *brevis*, Edw.

Summary.

1. The taxonomy and bionomics of the eight species and subspecies of *Eretmapodites* found in the Bwamba County, Uganda, are discussed.

2. Experiments are described to show that the larvae of these species are predatory, sometimes very actively so.

3. The females of all the Bwamba species bite man by day, sometimes in large numbers.

4. The larva and pupa of *E. inornatus*, Newst.; larva, pupa, and adult female of *E. penicillatus*, Edw.; larva, pupa, and adults of *E. ferox*, sp.n.; and larva and pupa of *E. leucopus* subsp. *productus*, Edw., are described for the first time, special reference being paid to the range of individual variation. The taxonomy of the various previously described species is also treated briefly.

5. Keys are provided for the identification of the known larvae, pupae, males, and females. These keys have been prepared in order to include the new material, and to delete certain unreliable characters previously regarded as of specific value.

Acknowledgements.

The writer wishes to thank Mr. G. H. E. Hopkins, Senior Entomologist (Medical), Uganda Protectorate, Mrs. G. R. C. van Someren and Dr. P. C. C. Garnham, Medical Research Laboratory, Nairobi, and Mr. J. O. Harper, Medical Dept., Kisumu, for loan of comparative material and for access to unpublished records.

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AN APPARATUS FOR HANDLING SMALL LIVING INSECTS.

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Investigations undertaken by the writer involved the determining and sexing of a large number of fleas daily, and it became clear that this would be a laborious process unless an apparatus could be designed which would facilitate separation and examination of the insects by making the process as automatic as possible. The technique finally used, though designed primarily for handling fleas, could be adapted for use with other insects of comparable size where examination under magnification is necessary.

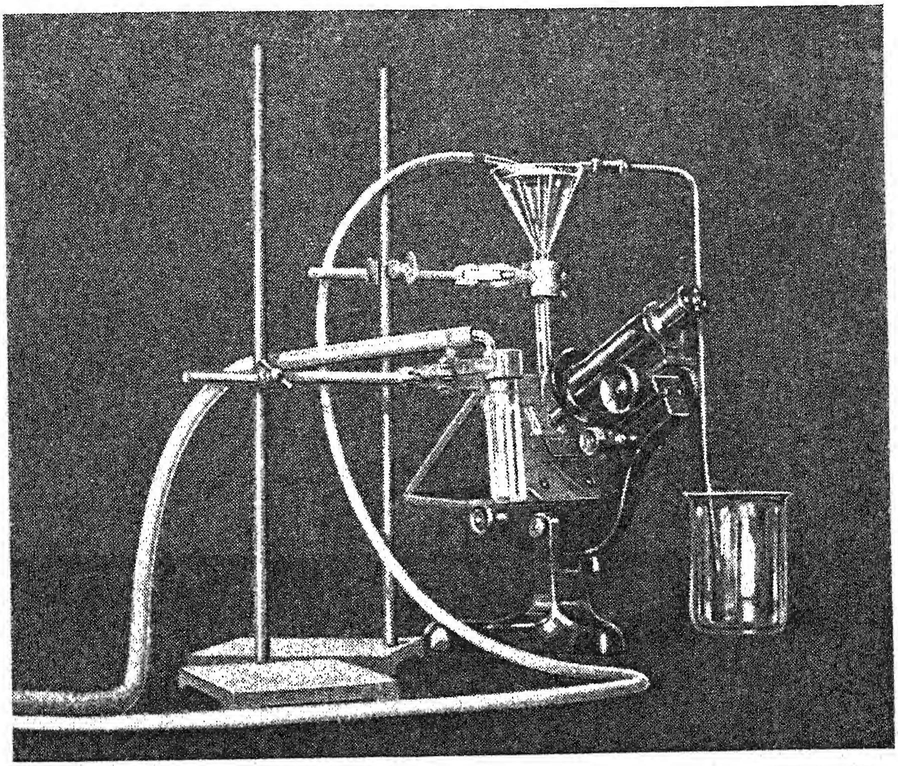

FIG. 1.

The general layout of the apparatus is shown in fig. 1, and the details are made clear in figs. 2 & 3. The intake section of the apparatus consists of a glass funnel (S), the *separator funnel,* closed at the top by a cigarette tin lid sealed in with paraffin wax, and of two glass tubes which lead into the cavity of the funnel through holes bored in the tin lid. One of these tubes (E), *the exhaust tube,* is attached by a long rubber tube to a filter pump; the other (I), the *intake tube,* is jointed in two places as shown in fig. 2, and is made of narrow bore tubing, not more than 2·5 mm. internal diameter, otherwise the current of air is not fast enough to lift the insects. The bottom of the intake tube lies about 2 ins. above the bottom of a large beaker.

The bottom of the separator funnel is sealed with wax into the delivery tube (D), which is made from a test tube, slightly wider than the stem of the funnel, drawn out in the middle to a diameter of about 2 mm. and cut off. The bottom of this tube ends just above a slide on a microscope whose stage is inclined at an angle of about 30° from the vertical, as shown in fig. 2.

Details of the construction of the slide are shown in figs. 3, *a*, *b* and *c*, which are a plan, a side elevation and an end elevation respectively. A wire, bent as shown in the figures, is attached along each edge of the coverslip with a little

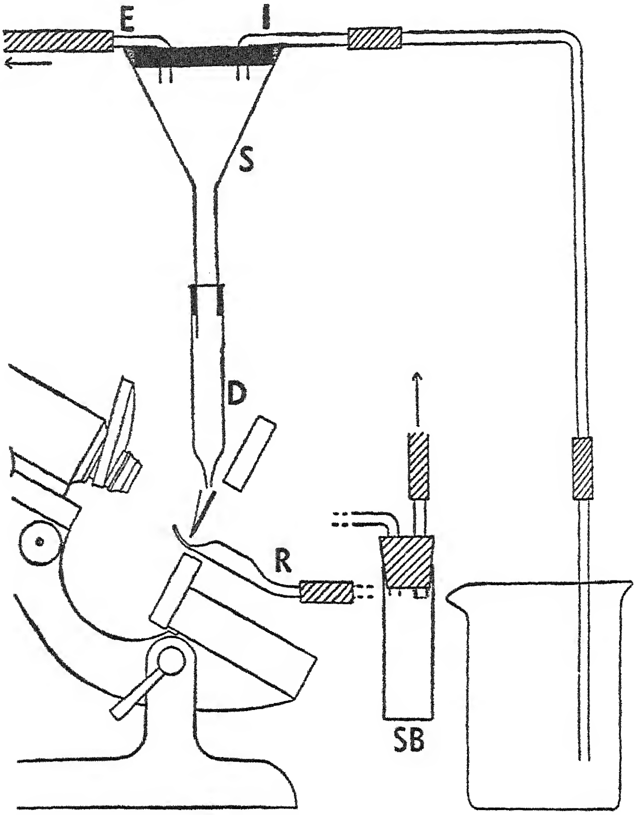

FIG. 2.—Diagram of the complete apparatus. D, delivery tube; E, exhaust tube; I, intake tube; R, recovery tube; S, separator funnel; SB, sorting bottle. Mechanical stage and details of slide and coverslip mechanism are not shown. The whole "intake group" lies in a plane at right angles to the paper and not as shown.

sealing wax or bitumen and forms a lever (L), by which the upper or lower edge of the slip can be raised from the slide. When the lever is not pressed, the slip is held in the normal position on the slide by two wire springs (S). The moveable end of each spring presses on the coverslip close to its edge, one on each side, and the fixed end of each spring is held firmly to the slide by sealing wax (W), shown in fig. 3, *b*, but not in the others. The pressure which it is necessary to exert on the coverslip by these two springs is slight and can be adjusted by putting more or fewer turns in the spiral or by using different kinds of wire, 25 S.W.G. nickel chrome wire, with ten turns in the spiral, has been found satisfactory. The coverslip is prevented from moving laterally by two parallel guides (G) of sealing wax, or glass strips cemented with balsam, the distance between them being

slightly greater than the width of the coverslip, and their inner faces smooth. On the under surface of the coverslip four narrow strips of another very thin slip are cemented with balsam, one along each edge. These raise the slip slightly from the slide and prevent damage to the fleas, but the strips must be very thin or the insects will move about under the coverslip.

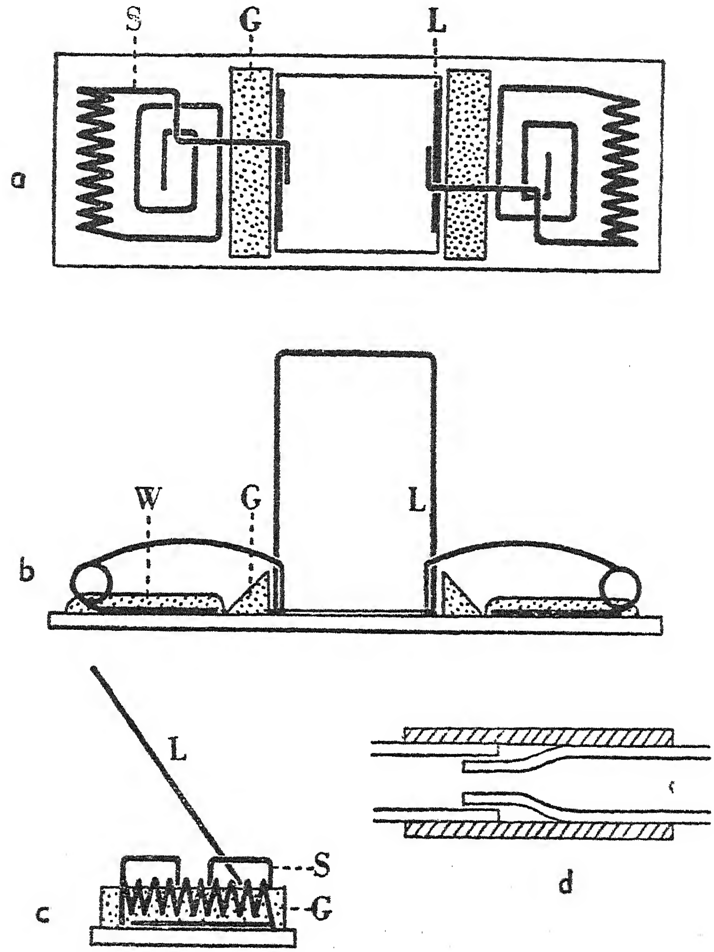

FIG. 3.—The slide and coverslip mechanism. a, plan; b, side elevation; c, end elevation; d, detail of joints in intake and recovery tubes; G, sealing wax guides for coverslip; L, coverslip lever; S, coverslip spring; W, sealing wax attaching spring to slide.

The whole slide is held on the microscope by the arms of a mechanical stage, though the latter is not shown in the figures for the sake of clarity. Two pieces of fine thread are attached across the opening in the stage, at right angles to each other and close to the under surface of the slide, in such a position that they cross in the centre of the field of the microscope.

Projecting through the aperture in the stage, near the bottom, is the top of the *recovery tube* (R). This is a piece of wider glass tubing, internal diameter about 8 mm., whose end has been drawn out into a wide, spatulate expansion.

This part of the recovery tube is not more than 2 in. long, and its lower end is drawn out and leads into a narrow tube by a flexible joint of the type shown in fig. 3, d, which allows the spatulate end to move up and down when caused to do so by the movement of the mechanical stage. The narrow part of the recovery tube leads away from below the stage to the *sorting bottle* (SB), which it enters through a rubber cork. An exhaust tube, its open end capped with voile, is also carried by the rubber cork and is connected by rubber tubing to another filter pump. In the author's work there were four sorting bottles as it was desired to separate the insects into four groups: males and females of two different species. The sorting bottle, which is an ordinary 1 in. × 3 in. specimen tube, is not in the position shown in fig. 2, but in a convenient place near the observer's left hand, and the recovery tube leads round from behind the stage to this position. Further, the intake and exhaust tubes, I and E, are not in the plane in which they appear for convenience in fig. 2, but they lie at right angles to this plane with the beaker to the right of the microscope as the observer uses it, where the intake tube is convenient for operation by his right hand.

To use the apparatus, the taps working the filter pumps are turned on and the fleas to be examined and sorted are put into the large beaker. The end of the intake tube is then brought near one of the insects in the beaker and the current of air sucks it through into the separator funnel, where the insect falls down the stem and into the delivery tube, and is suspended in the current of air drawn through the narrow opening at the bottom. The mechanical stage is now adjusted so that the bottom of the delivery tube is level with the top edge of the slide and vertically above the middle of the coverslip. The coverslip lever is now pressed slightly downwards with the index finger of the right hand, thus raising the upper edge of the coverslip from the slide, and the main exhaust tube, which should run conveniently close to the observer's left hand, is closed by pressure for an instant. Cessation of the flow of air allows the flea to drop through the bottom of the delivery tube and on to the slide. Directly the insect arrives on the slide the coverslip lever is released and the coverslip is forced back into place by the two springs, the flea being held between the coverslip and the slide, usually from a half to two-thirds of the way down. The position of the slide is then adjusted by the mechanical stage until the flea is opposite the point where the two threads cross. It is then in the centre of the field and can be examined through the microscope. A very low power ($1\frac{1}{2}$ in.) objective is shown in the diagram, but a $\frac{2}{3}$ in. objective can be substituted if desired.

After examination the correct sorting bottle is pushed on to the rubber cork which receives the recovery tube. This cork is held by a clamp at the top and at such a height above the bench as allows for convenient attachment and removal of sorting bottles. The attachment of a sorting bottle causes a current of air to be drawn through the recovery tube, and if now the coverslip lever is pressed slightly upwards, the lower edge of the coverslip is raised, the flea falls into the expanded end of the recovery tube and is drawn through into the sorting bottle. The latter is then removed and another insect taken from the beaker. The whole operation can, with practice, be performed in fifteen seconds.

The recovery tube used at first was not connected to a filter pump, the insects merely slipping through by gravity into the sorting bottle. This was found unsatisfactory, however, as the inclination of the top of the recovery tube cannot be steep enough and the fleas sometimes stick. Further, the sorting bottle had to be in an inconvenient position behind the microscope. The addition of the suction apparatus made the process of recovery after examination much more reliable and convenient.

For efficient working, those parts of the apparatus through which the insects pass must be kept clean and dry. A current of warm air, sucked through the

apparatus after it has been used, is helpful in this respect. It is also very convenient to have a duplicate slide and coverslip, so that if a large number of fleas has to be examined, the slide, which is apt to become a little damp and sticky, can be replaced and the used one cleaned.

The apparatus can also be used for other purposes. For instance, it is sometimes desired to separate a number of small insects and place each in a separate tube. For this purpose the microscope is removed and the insects, sucked up one at a time, are discharged each into a tube held below the delivery tube when the exhaust tube is momentarily pressed.

It was thought that the process of examination by this apparatus might harm the insects, particularly while they are actually held between the slide and the coverslip. Fifty newly emerged fleas were therefore put through the apparatus and subsequently kept in separate tubes under the same conditions as fifty other fleas which emerged on the same day but which were not put through the apparatus. No difference in longevity was found between the two series.

TESTS ON LOCUST BAITS IN SOMALIA*.

By Major F. B. Notley, M.Sc., A.I.C.T.A., F.R.E.S., R.A.M.C.

Introduction.

Throughout the world, wheat bran seems to have been the most popular carrier for locust and grasshopper baits. Wheat bran has, however, always been difficult to obtain in East Africa in sufficient quantity for large scale campaigns, and wartime conditions coinciding with a large outbreak of *Schistocerca gregaria* have made the position even more acute.

In Kenya since 1931 coffee parchment, with the addition of molasses, has been used as a satisfactory locust bait. The occupation of Italian Somaliland, now called Somalia, has put a very large area affected by *Schistocerca* under the control of the British Military Administration, and a locust control organisation has been built up to deal with it. The area consists of about 280,000 sq. miles and in the October-December, 1943, outbreak, practically the whole of this was affected. This involved the importation of very large quantities of coffee parchment bait from Kenya; actually nearly 45,000 bags were imported during 1943, and a further 60,000 bags during April and May, 1944.

The tests described below on substitute carriers for locust poison were carried out to avoid this burden on shipping, and also to lighten if possible the cost of the campaign.

Substances available.

Somalia is a semi-desert area, largely given over to nomadic, pastoral, camel-owning tribes, but possessing also three European areas of cultivation under irrigation on the banks of the Juba and the Webi Shebelli. The main native grain crop of sorghum is also grown along these two rivers, and in a large area between them with its centre at Iscia Baidoa. The following substances suggested themselves as possible carriers.

Bagasse.—Sugar-cane waste from the sugar factory at Villaggio. The annual production is about 8,000 tons per year, but at present all this is burned in the furnaces at the factory, and it would have to be replaced with wood fuel, cut from the surrounding bush.

Corn Cobs.—This is the waste maize cob after the removal of the seed. The estimated quantity available is 800 tons per year, but this would have to be collected in small quantities over a large area. The cobs are used as fuel or fed to cattle.

Rice Bran and Rice Grits.—About 160 tons a year are available, which is sold as pig food.

Rice Husks.—About 130 tons a year are available.

Wheat Bran.—About 70 tons a year, from wheat grown in Abyssinia, are available. It commands a high price as pig food.

Ground-nut Shells.—About 20 tons a year only available.

Jute.—A large quantity of spoiled jute was available, but preliminary tests showed this to be quite unsuitable. When the fibres are cut into short lengths, they tend to collect into large balls, and such a bait would be very difficult to spread.

Sawdust.—A few hundred tons of sawdust is available in Mogadishu from various sources.

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Tests on Adult Locusts.

At the beginning of the investigation locust hoppers were not available, and efforts to obtain them from Kenya were unsuccessful. The first material was obtained from the flying swarms which invaded Somalia from the North in October, 1943; and whilst efforts were made to breed these, preliminary tests were carried out using the adults as the test insect. In December, hoppers became only too readily available close to Mogadishu, where the work was done.

Method.—The method used was to confine the locusts in cages with glass top and front, gauze sides and back, and metal floor, about 15 in. cube. The same, or approximately the same, number of insects was placed in each. The same two baits, without poison but thoroughly moistened with water, were offered on small paper trays in all the cages, and the number of insects feeding on each recorded every five minutes. In the early experiments with adults up to 10 observations were made in each of 10 cages, but in later experiments with hoppers five observations in the same number of cages was found to be sufficient to give statistically significant results. The insects were starved for at least one day before being used as it was found that this induced them to feed readily at any time of the day. If the baits are offered when the locusts are not hungry, although some will feed, it appears mainly a matter of chance which bait they find first, and statistically significant results are rarely obtained.

It also appears that hoppers are attracted by their gregarious instinct to the bait on which most of their fellows are feeding. If the insects are hungry and many are feeding, the difference in attractiveness between baits is exaggerated by this factor.

It was not considered possible to deduce from the figures any quantitative figure for degree of attractiveness of the baits, especially as the experiments were carried out on different days and at different times of the day often with different insects. The only deduction made, therefore, is that one bait is better than another when a statistically significant result (P is lower than the 5 per cent. level) is obtained from observations of feeding when these two baits are offered together. Where a result is obtained that is not significant the two substances are recorded below as being equal in attractiveness. In this table and the one that follows the word Parchment is used for Coffee Parchment, and the letter " M " indicates that the bait so described was moistened with a 7 per cent. solution of molasses. In all other cases the bait is moistened with water.

The value of " t " is inserted in brackets; the 5 per cent. and 1 per cent. values of P are at 2·228 and 3·169 respectively.

Results of Tests with Adults.

The results of these experiments may be summarised thus:—

TABLE I.

Wheat Bran: = Rice bran (1·12); $>$ Bagasse (7·2), Corn cob (2·71).

Bagasse: $<$ Wheat bran (7·2); = Corn cob (1·18), Parchment M (0·99), Bagasse M (0·5); $>$ Parchment (4·2).

Parchment: $<$ Jute (4·38), Rice bran (4·7), Rice grits (3·2), Bagasse (4·2), Corn cob (6·2); = Rice husks (0·7), Sawdust (1·19); $>$ Ground-nut shells (2·23).

Parchment M: = Bagasse (0·99), Bagasse M (0·2).

Experiments with Hoppers.

These were carried out in the same way as those with the adults, except that larger numbers were used per cage. The number of observations per experiment was invariably five. In the following table the baits are arranged in order of what appears to be their attractiveness, and any bait which appears to be in its wrong class is shown in italics. It will be observed that a much greater proportion of significant results were obtained with hoppers.

TABLE II.

Wheat Bran: < nil; = Wheat bran M (0·0009); > Corn cob M (4·72), Rice bran (4·47), Corn cob (10·99), Bagasse M (20·75), Parchment M (20·55), Bagasse (7·49), Parchment (22·64).

Corn Cob M: < Wheat bran (4·72); = Rice bran (1·36); > Corn cob (14·67), Bagasse M (3·07), Parchment M (4·38), Bagasse (8·31), Parchment (9·10).

Rice Bran: < Wheat bran (4·47); = Corn cob M (1·36), Corn cob (0·64); Bagasse M (1·62); > Parchment M (2·95), Bagasse (7·56), Sawdust M (9·14), Parchment (2·28), Rice husks (10·29), Sawdust (10·48).

Corn Cob: < Wheat bran (10·99), Corn cob M (14·67); = Rice bran (0·64), Bagasse M (0·70), *Parchment M* (1·29); > Bagasse (10·28), Sawdust M (5·48), Parchment (2·55), Rice husks (4·67), Sawdust (6·39).

Bagasse M: < Wheat bran (20·75), Corn cob M (3·07); = Rice bran (1·62), Corn cob (0·70); > Parchment M (2·44), Bagasse (4·06), Parchment (7·20).

Parchment M: < Wheat bran (20·55), Corn cob M (4·38), Rice bran (2·95), Bagasse M (2·44); = *Corn cob* (1·29); > Bagasse (8·02), Sawdust M (3·94), Parchment (13·16), Rice husks (3·04).

Bagasse: < Wheat bran (7·49), Corn cob M (8·31), Rice bran (7·56), Corn cob (10·28), Bagasse M (4·06), Parchment M (8·02); = nil; > Sawdust M (4·11), Parchment (2·40), Rice husks (4·72), Sawdust (9·72).

Sawdust M: < Rice bran (9·14), Corn cob (5·48), Parchment M (3·94), Bagasse (4·11); = nil; > Parchment (5·48), Rice husks (4·99), Sawdust (4·15).

Parchment: < Wheat bran (22·64), Corn cob M (9·10), Rice bran (2·28), Corn cob (2·55), Bagasse M (7·20), Parchment M (13·16), Bagasse (2·40), Sawdust M (5·48); = Rice husks (0·38); > Sawdust (2·70).

Rice Husks: < Rice bran (10·29), Corn cob (4·67), Parchment M (3·04), Bagasse (4·72), Sawdust M (4·99); = Parchment (0·38); > Sawdust (4·70).

Sawdust: < Rice bran (10·48), Corn cob (6·39), Bagasse (9·72), Sawdust M (4·15), Parchment (2·70), Rice husks (4·70); = nil; > nil.

By adopting the order of preference as shown above, it will be seen that only one anomalous result is obtained; that is parchment M is shown as apparently equal to corn cob though worse than bagasse M which itself is shown to be better than parchment M. (This result appears twice.) The experiment, however, gave a result which was not significant, and, therefore, the anomaly is only apparent.

It will be noticed that a few possible combinations have not been tested, owing to pressure of other work, where the results should have been obvious. Thus wheat bran was not tested against sawdust or Sawdust M; but since it is better than, for instance, rice bran, which itself is better than either of these substances, the experiments were omitted.

Three substances used in the preliminary tests with adults were omitted in the tests against hoppers, namely jute, rice grits, and ground-nut shells. Jute, when finely chopped up, tends to adhere in large balls, and would be difficult to spread: it is in any case too valuable a product normally to use as bait. Rice grits consist of rice bran mixed with particles of broken rice, and appears to have just the same attractiveness as rice bran, but is more valuable as pig food. Ground-nut shells were less attractive to adult locusts than any other substance tested, absorbed very little water, and would be difficult to collect in quantity.

Two important considerations in a locust bait are the amount of water it will absorb and the ease with which the wet bait is spread. In a dry country, the water in a bait acts as a very strong attractant, and the ideal bait should absorb a great deal of water, dry slowly, and still be easily spread when saturated. In this respect bagasse was outstanding. The following figures were obtained for saturation point with water:—

5 gms.	bagasse	absorbs	20	gms.	water.
,, ,,	wheat bran	,,	12	,,	,,
,, ,,	sawdust	,,	12	,,	,,
,, ,,	corn cob	,,	10	,,	,,
,, ,,	rice bran	,,	8	,,	,,
,, ,,	parchment	,,	6	,,	,,

These figures represent complete saturation; for use in the field less water is added. Bagasse for instance is used with the addition of three times its weight of water.

Field Tests.

It is very difficult to devise satisfactory tests in the field, capable of statistical analysis, with bands of hoppers which are constantly moving about, especially when destruction of such bands is going on at the same time, and in fact no such tests were attempted. During the short rains campaign (Nov. 1943-Jan. 1944) small experimental baitings were carried out in the Villaggio area. The following extract from a letter by Major R. S. Mayers, Civil Affairs Officer, Villaggio, describes a typical result:—

> "Twenty-five pounds of bagasse bait with half a pint of molasses spread over an area of about four hundred (square?) yards. Hoppers were seen to feed the moment the bait was laid (between 1700 and 1800 hrs.). After 12 hours 100 per cent. of specimens showed that the bait had been eaten. After 24 hours there was about 65 per cent. mortality. Unfortunately between 24 and 36 hours this swarm was joined by another swarm so it was impossible to assess the total effectiveness, but after a further 24 hours a good percentage of the latter swarm was suffering from the effect of poison consumed with the carcasses of the poisoned first swarm. As mentioned, all tests were made in thick grass where there was plenty of other feed available."

During the "off" period, manufacture commenced on a large scale, and some 4,000 bags of bagasse bait were used in the Belet Wen, Bulo Burti, Villaggio, Afgoi area during the long rains campaign May-July, 1944. Opinions were unanimous that the bagasse bait was more attractive than the coffee parchment bait, remained attractive longer, and will ofter induce hoppers to stop and feed even when on the march. The following is extracted from a report on the campaign in this area by Capt. M. J. McCarthy, Asst. Locust Officer:—

> "This (bagasse) bait appears to have a far greater attraction than the coffee parchment for the hopper in all stages. Observation revealed that the hoppers will stop to feed on the new bait whilst on the march. Possible reasons being (1) Extra sweet content (2) Excellent absorption (3) Retention of moisture (4) Natural type of food (5) Easier to consume and more palatable than coffee parchment.

Distribution and handling. Easier to spread covering a greater area and distributes itself more evenly. Does not damage the sacks to the same extent as the old bait. Can be handled more easily. Altogether it appears to be the better bait and more suitable to local conditions."

Major Hallam, Asst. Locust Officer, reported:—

"From experience in the field, and personal use of bagasse as a locust bait, I would say that so far I have not used a bait so effective. It has many advantages as opposed to coffee parchment, and I found it even satisfactory when used in luscious grass, also in baiting on the banks of swamps, when the ground was moist. At all times I found that hoppers would take it in favour of local vegetation."

No adverse reports were received, and during the short rains campaign (Nov. 1944-Jan. 1945), over 60,000 bags of locally-made bagasse bait was used, and unanimously approved. In field practice molasses is added at the rate of two pints per bag.

A further advantage of the bagasse bait is its extreme lightness. A full 2½ lb. hessian bag weighs only 33 lbs. A sodium arsenite content of only 1·5 per cent. by weight is found to be effective. If it is assumed that a bag of any kind of bait can be spread over an equal area of hoppers, then a bag should contain the same weight of arsenite whatever the weight of the carrier. An arsenite content of only 8 ounces per bag appears to be extremely low compared with that used elsewhere.

Maize and Sorghum Stalks.

In November, 1944, two other substances, maize stalks and sorghum (durra) stalks, were tested by the cage method described above. No significant difference could be detected between maize stalks and bagasse ("t" $=0\cdot85$) but sorghum stalks were slightly but significantly more attractive than bagasse ("t" $=3\cdot51$).

Small scale field tests on ground sorghum stalks have shown satisfactory results, and large quantities of the stalks are now being collected both for large scale field trial and as a standby in case deliveries of raw bagasse do not come up to expectation.

Sorghum is grown almost entirely in three areas; the riverine strips along the Webi Shebelli and Juba and in the area Iscia Baidoa-Hodur-Bur Acaba. In the last area the stalks are fed to camels and cattle, and are an essential factor in the economy of the cultivators. In the riverine strips, however, owing to the presence of tsetse fly, animals are not kept and the stalks are mainly left to rot in the fields or burned. Collection of these stalks and transport to the factory for milling is, however, an additional difficulty and expense.

Manufacture.

The main difficulty in the production of the bagasse bait has been the reduction of the coarse product as received from the sugar factory to a sufficiently fine powder. After considerable experiment the following method has been adopted.

The bagasse as received is spread out in the sun to dry; in sunny weather this takes three to four days. It is then built into large stacks. If properly dried the stacks remain cool, and there appears to be little risk of spontaneous combustion. The stacks are not thatched or protected from rain, though this would be advantageous if possible; in practice any rain is absorbed by the top few inches of bagasse, which rapidly dries again, or can be rejected if the stack is being used immediately.

Before grinding, the bagasse is passed through cylindrical rotating sieves made of heavy wire cloth with square holes 1/16 of an inch in size. The cylinders are 6 feet long and 3 feet in diameter, and are sloped at about 30 degrees. The

amount of fine bagasse removed by these sieves varies, but is usually about 15 per cent. by weight: if the bagasse has been kept wet for a considerable period and hence rotted down somewhat it may be considerably higher.

From the sieves the bagasse passes to the milling machines. The output of each machine may be taken as averaging 20 bags per hour, though it varies considerably according to the state of dryness of the bagasse and the amount of wear on the cutting edges. The factory is capable of turning out over 30,000 bags of bait a month, but owing to various difficulties, has not yet exceeded 25,000 bags a month.

After grinding, the products both of the mills and the sieves are mixed on brick floors. Twenty-five bags of ground bagasse are evenly spread on one floor. Twelve pounds of sodium arsenite are dissolved in about four gallons of hot water, and this solution is then added to about 35 gallons of cold water standing in a drum by the mixing floor. The solution is then spread over the bagasse on the floor, and the whole turned over with spades until mixed, and then bagged.

Although the mixing is not by any means perfect, even by this method, it must be remembered that a further mixing will take place in the field when the water and molasses are added.

No attempt is made to dry the bagasse after mixing, but the bags are loosely stacked and turned over frequently. Usually they are sent out to district bait stores within a few days of mixing and get a further series of handlings by this means. The bait, however, shows no very great tendency to heat: after mixing it is only damp, not wet, since it contains less than two gallons of water per bag, although it is capable of absorbing more than nine.

A few tons of corn cobs have been dealt with in the factory, but it was found that they were very difficult to mill, and the output was only three or four bags per hour per machine; sorghum stalks on the other hand can be milled easily, though they have to be cut into short lengths before entering the machines, and the output of these is about 15 bags per hour per machine.

Costs.

The cost of a bag of bagasse bait has been estimated to be 2 Shs. 95 cents.* This estimate was made on the production up to 31st December, 1944, and is made up as follows:—

Bagasse	Shs. 0·2077
Arsenite	,, 0·4985
Bag (½ value)	,, 0·7500
Molasses	,, 0·4154
Labour and Management	,, 0·3612
Petrol, Oil, Grease	,, 0·1830
Depreciation on machinery, etc.	,, 0·4198
Sundries	,, 0·1172
	Shs. 2·9528

Many of these costs will be reduced by the increased production already achieved. The cost of a bag of coffee parchment bait in Kenya is Shs. 3·35. Handling and shipping charges bring the price up to over Shs. 16 per bag at Mogadishu. The saving is thus Shs. 13 per bag. Since the factory has already produced over 80,000 bags, the saving shown amounts to over £50,000, while the saving in shipping space amounts to 12,000 shipping tons. It is hoped to produce 200,000 bags at least during 1945, and the savings will be correspondingly greater.

My thanks are due to Major T. D. Lewis, Director of Public Works, and Capt. B. C. Arnold, P.W.D., for constant help and advice on the factory installation.

* The East African shilling is equivalent to the English shilling and is divided into 100 cents.

A FACTOR AFFECTING DIAPAUSE IN HYMENOPTEROUS PARASITES.

By F. J. Simmonds.

Whilst investigating the biology of parasites of the frit-fly (*Oscinella frit*, L., Diptera, Chloropidae) in North America with a view to introducing possible species for the biological control of this pest in Great Britain, extensive experimental work was done with one species of Chalcid, *Spalangia drosophilae*, Ashm. (Spalangidae), a parasite of frit puparia. During this work conditions inducing a state of diapause in the mature larvae were investigated. As with many other species, it was found that low temperatures during development favoured entry into diapause, whilst high temperatures favoured emergence of the progeny without arrest in development. However, other factors were found to have some important bearing in this respect. Some individual females produced progeny, all of which entered a state of diapause in the full-grown larval stage, others bred and ovipositing under identical conditions produced progeny all of which emerged without arrested development, others produced progeny that were mixed in this respect. This effect did not seem to be inheritable. The history of each individual female with respect to environmental conditions was found to have an important influence on the propensities of her progeny for entering diapause. These effects will be dealt with more fully at a later date. There was, however, one striking effect which has apparently not been noted before, and which it was felt was of sufficient interest to be recorded separately.

When females of *Spalangia* were allowed to oviposit at a constant temperature of 75°F., a number of them, as mentioned above, produced progeny a portion of which entered diapause as fully grown larvae. The distribution over the life of the female of individuals entering diapause and those emerging was peculiar. It was found that in the earlier part of her life the female laid eggs which produced progeny without arrest in development, and that as she grew older there was a progressive tendency for more of her progeny to enter diapause, even though external conditions had been kept constant.

Later, while investigating the parasites of the sugar-beet web-worm, *Loxostege sticticalis*, L. (Lepidoptera, Pyralidae), it was found that an ectoparasite of the fully grown larvae within their spin-ups, a new species of *Cryptus* (Ichneumonidae, Cryptinae), showed exactly the same effect as did *Spalangia*, and it was thought that this might prove to be a widespread effect having an important bearing on the general problem of the factors involved in the difficult question of diapause.

A table is given below showing the subsequent history of eggs laid throughout the life of individual females of both *Spalangia* and *Cryptus*. These examples have been selected to show the effect of ageing of the mother on her progeny, but the effect is shown to a lesser degree by a large number of the individuals under observation.

Immediately on emergence the females were mated with males about two days old. They were then kept isolated and supplied each day with an adequate number of suitable hosts so that the eggs laid on each day of the life of each female could be kept separate and their subsequent development recorded. That the effect is shown with both mated and unmated females is clearly indicated in the table. The *Spalangia* females were kept in $4\frac{1}{2}$ in. × 1 in. glass vials stoppered with a cork bearing damp cotton wool and a split raisin. (They also feed on the fluid exuding from the host from the punctures made by the parasite on stinging the host.) The *Cryptus* were kept in small wooden cages ($4\frac{1}{2}$ in. × $4\frac{1}{2}$ in. × 2 in.) with cheesecloth back and sides and a celluloid front, supplied with damp cotton wool, honey water on cotton wool, and a split raisin.

These results show that as the female gets older, the eggs she lays have a greater tendency to produce larvae which enter diapause. Further analysis of the results obtained with *Spalangia* indicate that, correlated with this increasing percentage of progeny entering diapause with increasing age of the parent female, there is a lengthening of the development time of those individuals which do emerge without arrested development. From the data so far obtained this effect is not apparent in *Cryptus*.

This whole matter will be discussed more fully at a later date, but it is apparent that in any consideration of the question of diapause, the physiological state of the parent female prior to and at the time of oviposition must be taken into account. Ageing must entail some physiological change in the ovarioles which alters the quality of the eggs produced, and this is reflected subsequently in development in an increasing tendency of the larval progeny to enter diapause.

TABLE I.

	Spalangia drosophilae									*Cryptus* sp. n.										
	Mated					Unmated				Mated						Unmated				
Age of female in days	Eggs laid per day	Male emergents	Female emergents	Individuals in diapause	Per cent. of living individuals in diapause	Eggs laid per day	Male emergents	Individuals in diapause	Per cent. of living individuals in diapause	Eggs laid per day	Dead	Male emergents	Female emergents	Individuals in diapause	Per cent. of living individuals in diapause	Eggs laid per day	Dead	Male emergents	Individuals in diapause	Per cent. of living individuals in diapause.
1	10	2	8	...		10	10	...		3	1	2	...	...		...	...	...	...	
2	6	4	2	...		2	1	1		4	2	2	...	...		1	1	...	...	
3	8	1	7	...	0·0	2	2	...	5·7	4	...	3	1	...	0·0	5	2	3	...	0·0
4	12	2	10	...		10	10	...		4	1	3	...	...		6	2	4	...	
5	9	1	8	...		11	10	1		10	6	1	3	...		8	4	4	...	
6	9	1	4	4		9	8	1		11	7	2	2	...		7	1	4	2	
7	13	...	4	9		14	3	11		6	2	...	4	...		9	2	5	2	
8	8	...	...	8	72·7	6	1	5	63·0	4	1	1	2	...	4·8	13	4	7	2	47·2
9	6	...	3	3		7	3	4		6	3	...	2	1		3	2	1	...	
10	8	...	...	8		10	2	8		10	3	3	4	...		19	6	2	11	
11	6	...	...	6		8	...	8		12	3	...	8	1		5	3	...	2	
12	4	...	...	4		5	...	5		4	1	...	1	2		10	7	...	3	
13	4	...	...	4	95·2	6	...	6	96·4	10	1	...	4	5	50·0	12	7	...	5	100·0
14	4	...	...	4		4	...	4		7	3	...	...	4		6	6	...	...	
15	3	1	...	2		5	1	4		6	5	...	...	1		5	4	...	1	
16	7	...	...	7		7	...	7		7	2	...	...	5		8	4	...	4	
17	5	...	...	5		3	...	3		7	1	...	...	6		8	5	...	3	
18	6	...	...	6	100·0	7	...	7	100·0	5	...	...	...	5	95·2	4	2	...	2	93·8
19	6	...	...	6		6	...	6		...	...	...	...	...		5	3	...	2	
20	4	...	...	4		7	...	7		5	...	...	1	4		8	3	1	4	
21	6	1	...	5		6	...	6		5	1	...	1	3		6	5	...	1	
22	5	...	...	5		4	...	4		1	...	...	...	1		1	1	...	...	
23	5	...	...	5	96·4	7	2	5	88·0	...	...	...	...	...	80·0	6	2	...	4	100·0
24	4	...	...	4		5	1	4		...	...	...	...	...		1	...	...	1	
25	8	...	...	8		3	...	3		...	...	...	...	...		8	8	...	...	
26	2	...	...	2		4	...	4		...	...	...	...	...		1	1	...	...	
27	5	...	...	5		3	...	3		...	...	...	...	...		...	...	...	...	
28	4	...	...	4	100·0	5	...	5	100·0	3	3	...	...	...		...	...	...	...	
29	2	...	...	2		3	...	3		...	...	...	...	...		...	...	...	...	
30	5	...	...	5		6	...	6		...	...	...	...	...		...	...	...	...	
31	4	...	...	4		2	...	2		...	...	...	...	...		...	...	...	...	
32	7	...	...	7		5	...	5		...	...	...	...	...		...	...	...	...	
33	2	...	...	2	100·0	...	...	...	100·0	...	...	...	...	...		...	...	...	...	
34	3	...	...	3		...	...	...		...	...	...	...	...		...	...	...	...	
35	5	...	...	5		1	...	1		...	...	...	...	...		...	...	...	...	
36	2	...	...	2		1	...	1		...	...	...	...	...		...	...	...	...	
37	1	...	...	1		2	...	2		...	...	...	...	...		...	...	...	...	
38	3	...	...	3	100·0	1	...	1	100·0	...	...	...	...	...		...	...	...	...	
39	2	...	...	2		1	...	1		...	...	...	...	...		...	...	...	...	
40	...	...	...	...		1	...	1		...	...	...	...	...		...	...	...	...	

Variation of numbers of progeny going into diapause with age of parent female. Daily oviposition and subsequent history of each day's eggs of single mated and unmated females bred and kept at a constant temperature of 75° F.

ERADICATION OF *GLOSSINA* IN THE NABOGGO VALLEY, GOLD COAST.

By J. L. STEWART, M.C., B.Sc., M.R.C.V.S., F.R.S.E.

This work was found necessary when the Pong-Tamale Veterinary Laboratory and Livestock Farms were built in 1930-31 in the Naboggo Valley. The site was chosen because of ample water and abundant available ground.

No sooner were the cattle moved from the old Tamale farm than trypanosomiasis began to appear. Dr. K. R. Stacey Morris, who was consulted, made a survey and submitted recommendations for the eradication of the fly, which comprised *Glossina palpalis* and *G. tachinoides*, the latter predominating. The cattle of the Gold Coast are small unhumped dwarf animals which have a certain resistance to trypanosomiasis, a resistance which can be improved by scientific breeding. While trypanosomiasis is not usually lethal to these cattle, it is the limiting factor to improvement and inhibits such breeds as European cattle and even the African Zebu. However, so considerable was the incidence of fly in the Naboggo Valley that clinical trypanosomiasis appeared in the Pong-Tamale herd with considerable mortality; it must be stressed that the local cattle are resistant though not immune and that resistance appears to break down when cattle are exposed to a certain intensity of exposure to tsetse or when conditions are adverse. The writer has worked for over fifteen years on this problem and is convinced that the correct line of attack is the elimination of the fly and not the creation of resistant breeds of cattle. These are handicapped by the limitations imposed by exposure to a pathological Protozoan, whereas elimination of the fly would mean that improved and better types of cattle could be maintained. The local dwarf race could then be allowed to disappear just as dwarf cattle have disappeared in other parts of the world. Thus it will be clear that the importance of the tsetse problem to the livestock industry is considerable and means the difference between a stunted uneconomical animal and a passable economic one, and this also includes sheep and goats.

The River Naboggo rises some forty miles due East of the River Volta in the Northern half of the Northern Territories of the Gold Coast. It is slow running and meanders considerably. During the dry season from early November until the rains are well begun in June, it does not flow, though long reaches contain water. In 1931 the fringing "bush" within its banks, which was continuous along its full course, was infested with tsetse fly. The original idea was to clear the portion of the river within easy reach of Pong-Tamale station which was about three miles distant on both the north and west, the river taking a right angle bend about five miles north-west of it. Barrier clearings were proposed at either end of the clearing to keep out fly. As the work progressed and its value became apparent, the idea arose of clearing the entire valley, and in 1938, after the Pong-Tamale clearing had been completed as originally planned, the Dagomba Native Administration provided funds to enable additional labour to be employed. This extension also meant the clearing of two tributaries, the Gushie and the Zoggaw rivers, about 25 and 15 miles long respectively, the latter running through a thickly populated area.

Originally very drastic clearing was done. Not only were all the trees and shrubs within the river banks rigorously eliminated but such trees as *Mitragyna inermis* were cleared from all swamps and re-entrants around the river. As time went on, this was modified and clearing is now limited to the trees actually within the banks of the river. These trees, with the odd exceptions which prove the rule, are degenerate forest species so that when a whole river is cleared from the source downwards they cannot regenerate and thus the clearing is permanent. This is an important point in the elimination of flies of the *G. palpalis* group, which require low shade and humidity for their existence. The method employed is cutting during the dry season from November to March inclusive, all débris being

retained and cut and piled on top of the roots. In April-May burning is carefully done, the greatest care being taken to get an intense burn on the top of the roots and to use all débris to the full. This burning, if done efficiently and followed by the wet season full river, kills the stumps most effectively, but if done carelessly the final result can be worse than the original. In the first year of the clearing, an enthusiastic political officer provided forced labour to do some additional clearing and that half mile has given more trouble and re-clearing than all the rest of the river. Efficient clearing requires skilled labour and great care but is well within the compass of Africans. The Naboggo clearing has been in the executive hands of the head African assistant, Mr. Issaka Abdulai, who has worked for fifteen years with the absolute minimum of supervision, and the credit is due to him for its executive efficiency. After some time, experiment proved that it was not necessary to clear the wet savannah trees and shrubs such as *Mitragyna inermis*. The degenerate forest trees grow in layers, and where the fringing "bush" is thick, there are three. Where it is thin there is but one composed of the hardiest species, of which the commonest are *Antidesma venosum, Dissomeria crenata,* and *Garcinea baikiana*. In the inside the most common are *Cynometra vogelii, Dialium guineense, Sesbania punctata,* while in the middle are found trees such as *Morelia senegalensis, Cola laurifolia,* etc., though the trees are not always constant in this distribution. The practical application of this is that once the "fringing bush" within the banks of rivers is cleared efficiently, it cannot regenerate provided that the whole river is cleared and that no seeds can be water-borne from the upper reaches. It has been found that the savannah trees do not tend to extend into the actual banks of rivers once they are cleared nor are they likely to do so because the banks appear to be too wet for them; it is probable that the inhibiting factor is the flood period when trees within the river banks remain in a state of submergence for a long time. In 1941 when clearing the Zoggaw tributary, a length of fringing bush just over 200 yards long was left intact in a reach of the river which dries for the last two months of the dry season, the vegetation being the hardier riverine trees. Flies from surrounding cleared parts crowded into this belt, and a catch of 50 flies per boy per day was reached. In 1942 four fly boys during a week in June caught 8 flies only; in September, 1943, one fly was caught; and on several occasions in 1944 no flies were found, and in 1945 it was cleared. This experiment can be carried on at a more convenient place.

The predominant fly in the Naboggo Valley was *G. tachinoides*; *G. palpalis* was found mainly at river crossings and watering places frequented by human beings, including the Upper Zoggaw tributary which waters a thickly populated valley. It would seem that the predilection of *G. palpalis* for human blood may explain this distribution. In 1931-32 the percentage of *G. palpalis* on the Naboggo was 5 per cent., in 1933-34 under 2 per cent., and in 1934-35 less than 0·5 per cent. This is explained by the fact that the uncleared part by that time was almost entirely in uninhabited terrain where only a few fishermen penetrated. On the Zoggaw river a steady 4 per cent. of *G. palpalis* was found until all fly had been eliminated. There was always a certain fly population on the Naboggo before clearing which varied according to conditions, being heaviest from March to July, then falling in August-October due to flooding and lowest from November to March inclusive. It was found that when the river banks became submerged that flies lived in the canopies of the riverine trees and actually pupated in the nooks and crannies of these trees wherever there was a suitable deposit of earth or silt. The fly distribution was based on the number of flies caught per boy per hour, but the November-February period may have been assessed too low as at that time the dry harmattan wind blows, and on days when it is strong, flies remain quiescent in crannies; if a fine calm day occurs in the midst of this period, the fly-boy-hour catch rises markedly. However, it is a useful rough and ready method of estimation which is handy in practice. Fly boys have been found more useful for

catching and identification of flies than traps. Most types of traps have been tried with disappointing results; no trap has ever caught as many flies as one boy. An experiment carried out with coloured screens of khaki, grey and dark brown, 4 ft. 6 in. by 3 ft. and held by fly boys in an uncleared portion of river proved interesting. Each boy held a screen in front of himself and caught the flies which landed on the screen only. One boy without a screen acted as control. The catches over a period of two months worked out with khaki—15·7 flies per day; grey—21·6; dark—29·5; and boy alone 32·8; so that the fly boy working alone with a net is more effective than traps.

The range of flight of flies of the *G. palpalis* group is a matter of some little importance to those involved in eradication by clearing. In the dry season, it is limited and flies have rarely been found more than 500 yards from tsetse cover. However, in the rains, it would seem that ten miles may be accepted as the range of flight of both *G. palpalis* and *G. tachinoides*. Although the whole valley has now been cleared, the River Volta is slightly under ten miles from Pong-Tamale as the crow flies. In September, when flooding is at its height and conditions are generally at their wettest, a few flies are invariably caught in the area to the west of the main road in which is the main farm and laboratory area, but never have any flies from the Volta been caught on the east side of the road. Every year large numbers of flies are caught, marked and liberated at each end of the clearing so that it would be possible to ascertain where flies caught in the area were coming from. In the early years most were from the east but now that the upper Naboggo has been cleared and flies eliminated, the only remaining source is from the Volta and various ponds, re-entrants and such like around the confluence of the Naboggo River with the Volta. Further clearing will be carried out in that area with all subsidiaries cleared and perhaps a couple of miles of the Volta, which has very thin fringing bush at the part in question. In 1944 the Pong-Tamale area was over-stocked owing to over a thousand army bullocks not being removed when expected, so that at the height of the flood period when low-lying ground, normally good grazing, is flooded, these cattle had to go far afield into the area not far removed from the River Volta. They were then easily accessible to wandering tsetse which followed them into their home area. In consequence numerous bullocks became infected and 10 per cent. died. Moreover, one herd of improved cattle bred at Pong-Tamale which grazed nearest to the army cattle also became infected. These happened to be a type which is highly resistant to trypanosomiasis, N'Dama by name, and although a couple of dozen clinical cases appeared, there were no deaths. Fortunately the improved Sanga herd, with its high zebu strain and which is comparatively susceptible to trypanosomiasis, did not contract infection as flies did not gain ingress to their area. In 1943 there was a large army collecting centre for imported cattle in the Naboggo valley, four miles north of Pong-Tamale on the banks of the river. The imported cattle, which were zebus from the French Sudan, travelled south from the northern frontier, and at the crossing of the White Volta nearly seventy miles north, were attacked by *G. submorsitans* which followed the herds to Naboggo. The trypanosomiasis infection set up by this fly appeared to be particularly virulent as most local herds in villages through which these imported cattle passed, became infected, with high casualties. Normally these cattle have a high resistance and seldom succumb. The infection was mainly *Trypanosoma vivax* which is responsible for over 90 per cent. of animal trypanosomiasis in the Gold Coast, and is normally very responsive to treatment and not normally lethal to the local unhumped cattle. No *G. submorsitans* penetrated south of the Naboggo because they were exterminated by the fly boys, and the cattle remained several days in that camp.

The effect of the clearing on the valley is naturally of some little importance. Erosion, for instance, was feared, but it has not occurred because the river is very slow running and meanders extensively. A profuse growth of grass occurs very quickly after clearing and holds the banks well. However from observation, the

writer is of opinion that erosion will be a very serious problem on rivers which run at any speed and that counter measures will be necessary. Clearing of a tropical river of its fringing bush should be followed by development. It is not suggested that every such river should imitate the Tennessee Valley scheme, but there is no reason why water conservation, anti-flooding measures and perhaps irrigation should not be carried out. On the Zoggaw tributary of the Naboggo River, which has a heavy population, two weirs were run across the river which is normally dry by February and remains so until the early rains in April or May, the local women having to walk from six miles upwards to the parent Naboggo River to carry water. This has resulted in two long reaches of about a mile each being held up and provides adequate dry season water for the villages in question. Even with nothing but clearing of the Naboggo Valley and the two dams on this tributary, people have returned to the valley and the villages are more heavily populated than they were prior to the clearing. At one time the valley had been thickly populated but when the Department moved its station at Pong-Tamale, the riverine villages, most of which are from two to four miles from the actual river and are on higher ground, were nearly all in process of reduction of population and several had disappeared and were in ruins. There is little doubt that this was due to human trypanosomiasis. The depopulation appears not to have begun before the beginning of the century, and the author considers that it was caused by the inhabitants having to go to the river for water during the dry season while prior to that they drew water from the old so-called "aboriginal cisterns", which were underground tanks constructed in valleys near the villages by some previous more enlightened inhabitants. These were not maintained by the present inhabitants and finally silted up. The fact that concentrations of *G. palpalis* were found at all the places on the river where villages were in the habit of drawing water and washing provides contributory evidence. However, there is now a considerable drift back to the villages, and numerous herds of cattle appear in the dry season for grazing and water. The valley floods heavily from August to October so that low-lying land cannot be put to any permanent use. The dry season water level has been maintained.

The question of maintenance of clearings is most important. In the case of the Naboggo Valley this has been very easy. The main point is that the initial clearing must be efficient; the roots of the riverine flora must get a hot burn as unless the primary burning is done thoroughly re-growth will be considerable. Population in the Naboggo Valley is scanty near the river; hence there was little trouble about people removing the débris for fire-wood but in another clearing near the town of Yendi the writer had great trouble in securing sufficient débris to get a good burn owing to its removal for fire-wood. For some years after clearing, a little work is required to keep down the few shrubs and trees which may regenerate, and these are mainly *Mitragyna inermis, Mimosa asperata, Combretum acutum* and *Vitex chrysocarpa*.

Without clearing, the Naboggo and similar valleys are not safe for cattle in the dry season, because although the local cattle have a certain resistance, it is only relative resistance. Whenever such cattle were taken to uncleared valleys, there was invariably some mortality from trypanosomiasis so that often the choice was between starvation at home and disease in the valleys. In 1945, a severe drought occurred with the usual rains three months later; the Department had nearly three thousand cattle in the Naboggo valley, there were nearly two thousand local cattle while several thousand others came in from elsewhere; grazing was somewhat thin towards the end but in spite of this, large numbers of cattle maintained fair condition. Thus the value of a tsetse cleared valley to cattle alone under existing primitive conditions is considerable.

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THE USE OF DDT AS A MOSQUITO LARVICIDE ON FLOWING WATER.

By Major C. R. Ribbands, R.A.M.C.

Introduction.

These experiments are part of the series made by No. 2 Entomological Field Unit, R.A.M.C., on the potentialities of DDT (dichlor-diphenyl-trichlorethane) for military purposes. A report on the use of DDT as a mosquito larvicide on still water has already been published (Ribbands, 1945).

Two of the experiments now described involved the treatment of small streamlets, or irrigation ditches, and these were conducted at Nikaweratiya, Ceylon, in April, 1944. The third experiment was the treatment of an *Anopheles minimus* infested river, and was made at Hilika Tea Estate, Doom Dooma, Assam, in June, 1945. Sgt. J. A. Aspey bore the brunt of the routine work involved.

Methods.

The treatments were made with crude DDT (para para content 70-75 per cent.). For the ditch treatments this was dissolved in waste engine oil, and for the river treatment in a mixture of 75 per cent. kerosene and 25 per cent. waste engine oil. All treatments were made by adding the measured dose to the stream at one point only. The smaller doses were run in from a pipette, and the larger doses poured on from a petrol can. The whole dose was applied at one time and the success of the treatments was judged by larval sampling. Single dips were made at one foot intervals along the stream edge, both immediately before treatment and on successive days after treatment. The same worker, or team, took the samples both before and after any treatment.

Treatments of Irrigation Ditches.

Two irrigation channels were selected, both of which were fairly straight, and flowed along the edge of paddy fields. The fields were fallow and neither channel was disturbed during the experiments. In both cases the stream was dipped at one foot intervals, alternate dips on opposite edges, both before treatment and one day after treatment.

Experiment A.

This was made on an open, even, sunny channel, approximately 2 ft. in width and 9 ins. deep at the centre. Both edges were thickly overgrown with short grass-like vegetation—*Hygroryza aristata*—which extended from 6-9 ins. into the gently sloping sides of the stream.

A sample of the Anopheline population comprised 90 per cent. *A. hyrcanus*, 6 per cent. *A. aconitus*, with the remainder a mixture of *A. jamesi*, *A. vagus*, and *A. barbirostris*. Culicines were not identified.

The experiment was conducted on a straight length of 430 ft. The upper portion was used as an untreated control stretch. Treatments were applied 300 ft. above the lowest end of the experimental area. In two of the experiments an equivalent dose of waste oil, without DDT, was applied to an intermediate stretch.

The results are shown in Table I.

Experiment B.

This irrigation channel was approximately 18-24 ins. wide and 9 ins. deep at the centre. It was partially shaded by bushes. Both edges were covered with grass and weed, but the sides sloped rapidly and the weedy edge was usually 3-6 ins. wide.

The experimental stretch was 1,020 ft. in length. The stream flowed rapidly at the upper end, but slowed down during its course because much of the water was seeping through the banks into the adjoining rice field.

The measured rate of flow was 50 ft. per minute over the upper 300 ft., 33 ft per minute 450 ft. downstream, 25 ft. per minute 700 ft. downstream; for the lowest 200 ft. the stream was very sluggish. Rates of flow were measured by timing the passage of small floating sticks between fixed points.

TABLE I.

TREATMENT OF SHORT DITCH (Experiment A).

Numbers of first-stage Anophelines are stated in brackets after total number.

Treatment	Rate of water flow at time of treatment	—	Number of Larvae				
			Untreated portion 50 ft.	Waste Oil only 80 ft.	Treated portion: Nearest 100 ft.	Treated portion: Middle 100 ft.	Treated portion: Remotest 100 ft.
A.1. 5 c.c. 5% DDT in waste oil (=0·007 ozs. DDT)	12 ft. per minute	ANOPHELINES: Before ...	42 (13)	104 (17)	100 (24)	100 (27)	111 (26)
		After ...	60 (12)	147 (18)	38 (11)	39 (11)	56 (12)
		Survival ...	143%	141%	38%	39%	50%
		CULICINES: Before ...	83	219	335	314	279
		After ...	64	191	239	230	152
		Survival ...	77%	87%	71%	73%	55%
A.2. 10 c.c. 5% DDT in waste oil (=0·014 ozs. DDT)	12 ft. per minute	ANOPHELINES: Before ...	43 (10)	94 (15)	109 (21)	96 (17)	58 (12)
		After ...	46 (5)	59 (3)	2 (0)	2 (0)	3 (0)
		Survival ...	106%	63%	2%	2%	5%
		CULICINES: Before ...	139	170	203	129	249
		After ...	90	140	6	3	10
		Survival ...	69%	82%	3%	2%	4%
			Untreated portion 130 ft.				
A.3. 10 c.c. 5% DDT in waste oil (=0·014 ozs. DDT)	15 ft. per minute	ANOPHELINES: Before ...	133 (33)		75 (34)	95 (31)	103 (22)
		After ...	132 (10)		8 (1)	...	...
		Survival ...	99%		11%	nil	nil
		CULICINES: Before ...	171		163	119	112
		After ...	229		74	40	19
		Survival ...	133%		45%	34%	17%
A.4. 0·014 ozs. DDT mixed in wood ash.	20 ft. per minute	ANOPHELINES: Before ...	133 (25)		138 (21)	143 (29)	120 (15)
		After ...	133 (33)		75 (34)	95 (31)	103 (22)
		Survival ...	100%		54%	66%	86%
		CULICINES: Before ...	210		225	189	250
		After ...	171		163	119	112
		Survival ...	81%		73%	63%	46%

The Anopheline population samples varied thus:—

Upper 220 ft.: 40 per cent. *A. hyrcanus*, 35 per cent. *A. aconitus*, with some *A. barbirostris* and *A. subpictus*.

Middle 500 ft.: 75 per cent. *A. aconitus*, 25 per cent. *A. hyrcanus*.

Lower 300 ft.: 65 per cent. *A. hyrcanus*, 22 per cent. *A. vagus*, with some *A. aconitus* and *A. barbirostris*.

The results are presented in Table II.

TABLE II.

TREATMENT OF LONG DITCH. (Experiment B.)

Numbers of first stage Anophelines are stated in brackets after total number

Treatment	Rate of water flow at time of treatment	—	Number of Larvae: Untreated Portion 120 feet	Treated portion: Nearest 300 ft.	Treated portion: Middle 300 ft.	Treated portion: Remotest 300 ft.
B. 1 10 c.c. 5% DDT in waste oil (=0·014 ozs. DDT).	*See* text	ANOPHELINES:				
		Before ...	89 (14)	169 (47)	97 (34)	242 (83)
		After ...	25 (2)	14 (0)	17 (1)	6 (3)
		Survival ...	28%	8%	17%	2%
		CULICINES:				
		Before ...	25	33	18	134
		After ...	3	8	1	22
		Survival ...	12%	24%	6%	16%
B. 2 20 c.c. 5% DDT in waste oil (=0·028 ozs. DDT).	*See* text	ANOPHELINES:				
		Before ...	16 (6)	33 (17)	63 (17)	129 (40)
		After ...	19 (4)	1 (1)	1 (1)	—
		Survival ...	119%	1%	1%	Nil
		CULICINES:				
		Before ...	43	84	184	881
		After ...	115	67	59	24
		Survival ...	2%	80%	32	3%

The conclusions drawn from the results of Experiments A and B, *which are arrived at after weighting the catches in the treated stretches to counterbalance the changes found in the untreated controls,* are as follows:—

(i) 10 c.c. of 5 per cent. DDT in waste engine oil (0·014 ozs. DDT) eliminated 97 per cent. of Anopheline larvae through a distance of 100 yards below the point of application, with the stream flowing at 12 and 15 ft. per minute (Expts. A.2, A.3).

(ii) The same dose eliminated 29 per cent. of Anophelines through the same distance, with the stream flowing at the rate of 35-50 ft. per minute (B.1).

(iii) The same dose was 96 per cent. effective against Culicines when the stream flowed at 12 ft. per minute (A.2), 74 per cent. effective at a flow of 15 ft. per minute (A.3), and ineffective at a flow of 35-50 ft. per minute (B.1).

(iv) 20 c.c. of 5 per cent. DDT in waste oil was 99 per cent. lethal to Anophelines through a distance of 300 yards below the point of application, in a stream of variable flow, and was 97 per cent. effective through the uppermost 100 yards where the stream flow was at the rate of 33-50 ft. per minute (B.2).

(v) This same dose was 92 per cent. effective against Culicines through the 300 yards (this effect is exaggerated because most of the Culicines were in the sluggish portion), but was only 52 per cent. effective through the uppermost 100 yards, where the stream flow was 33-50 ft. per minute (B.2).

Conclusions i-iii indicate that the required dose is proportional to the rate of flow of the stream, and conclusions iv-v confirm this deduction.

(vi) Where the rate of flow of the stream did not vary throughout its length, kills of Culicines were considerably greater 200-300 ft. below the place of treatment than they were within 100 ft. of this point (A.1, A.3, A.4).

(vii) 0·014 ozs. DDT, mixed as a 2 per cent. powder with wood ash, was much less effective than the same quantity of DDT in oil (Cf. A.2 and A.3 with A.4); waste engine oil without DDT was quite ineffective in small doses (A.1, A.2).

(viii) DDT in oil was either lethal to Anopheline eggs or it clung to the eggs and killed all larvae emerging from them, because the reduction in the number of first stage larvae found after treatment was of the same order as that of the other instars (A.1-3. B.1-2). Buxton (1945 *a*) states that DDT does not kill insect eggs, though traces of it may kill after emergence, and I have already published a similar conclusion (Ribbands, 1945).

(ix) DDT in wood ash had no effect on Anopheline eggs (A.4).

(x) Culicines were less vulnerable to DDT than Anophelines.

Treatment of a River.

This experiment was conducted on the Hapjan River, a tributary of the Dibru River. The experimental portion was thirty feet in width and pursued a winding course through scrub and ricefields. It had well-defined banks, and was both deep and silty. Portions of the banks were steep and inaccessible, and in other parts the edge of the stream was bare of vegetation. As the depth of the river fluctuated very considerably with storms, stretches (along one bank only) were chosen which had sufficient grasses and vegetation to provide anchorage for Anophelines at all times. The rate of surface flow averaged 75 ft. per minute.

The Anopheline population during experiments C.1-3 consisted almost entirely of species of the group *Myzomyia* (*A. minimus*, with some *A. varuna*, *A. fluviatilis* and *A. aconitus*), but during C.4 approximately 40 per cent. of the population was of other species (*A. kochi*, *A. annularis*, *A. hyrcanus*). The very few Culicines were ignored.

Selected stretches were dipped at one foot intervals both before and on successive days after treatments. There was a 100 ft. control stretch, 100 yards above the point of treatment, and there were fifteen treated lengths, arranged as follows:—

Designation	i	ii	iii	iv	v	vi	vii	viii	ix
Length in feet	35	35	25	25	30	40	35	50	50
Average distance below treatment in yards.	105	216	262	489	518	602	667	937	1024

Designation	x	xi	xii	xiii	xiv	xv
Length in feet	95	35	20	35	20	40
Average distance below treatment in yards.	1294	1392	1709	1892	2209	2284

In the results now tabulated stretches ii-iii, iv-vii, viii-ix, x-xii, xiii-xv have been grouped together. As larvae were not found evenly in the various stretches, the average distances, as given in Tables III and IV, were calculated by multiplying the number of larvae found in each stretch before treatments by the average distance of that stretch from the point of treatment, adding all these values together, and dividing this quantity by the total number of larvae in the group of stretches. For all experiments the DDT was dissolved in a mixture comprising 75 per cent. kerosene and 25 per cent. waste engine oil, and was poured into the river at one time at arm's reach from the edge of the bank, and on the side at which all the dips were made. Within 50 yards from the point of treatment the oil film had spread to the other bank also.

The results are presented in Tables III and IV. No examinations could be made still further downstream, and it is possible that the actual distance of effective treatment considerably exceeded the demonstrated distance.

TABLE III.

Number of Larvae and Pupae surviving after treatment of a river (Experiment C).

Dose of 5% DDT in oil	Time of dipping	Number in untreated control	Number in treated portion					
			Average distance from point of treatment					
			103 yds.	252 yds.	540 yds.	965 yds.	1400 yds.	2150 yds.
C. 1	Day before dose ...	27	8	23	42	63	34	36
1 pint ...	2 days after dose...	29	5	12	25	11	7	12
	3 days after dose...	19	5	4	32	12	13	35
C. 2	Day before dose ...	31	4	15	32	21	49	99
2 quarts ...	1 day after dose ...	89	7	14	32	4	13	12
	2 days after dose...	32	7	5	11	0	15	3
	3 days after dose...	36	6	3	16	8	24	12
C. 3	Day before dose ...	20	0	21	16	17	13	6
2 gallons ...	1 day after dose ...	31	0	0	0	0	0	0
	2 days after dose...	16	0	0	0	0	0	0
	3 days after dose...	39	0	1	15	7	0	0
	4 days after dose...	80	15	2	23	2	7	10
C. 4	Day before dose ...	33	10	21	9	13	24	12
2 gallons ...	1 day after dose ...	40	1*	1	0	0	0	1*
	2 days after dose...	50	0	2	0	0	0	0
	3 days after dose...	45	2	1	2	1	0	0
	4 days after dose...	56	1	3	11	0	0	4

* Pupae, not larvae

These results show that there was an increase in the number of larvae in the untreated control during the course of each experiment. No allowance has been made for this in drawing the following conclusions:—

(i) On two occasions full larval control was obtained through a length of 2,280 yards of river edge by the use of 2 gallons of 5 per cent. DDT in oil (=1 lb. DDT). On the first occasion no larvae or pupae were found until the third day after treatment, and on the second occasion only 3 Anophelines were found on the day after treatment, compared with 89 on the previous day—and two of these three were pupae.

(ii) Maximum larvicidal effect was not obtained at the point of treatment, but at a considerable distance below this point. In Expt. C.1, although the dose was so small that it was only partly effective, the maximum effect was obtained in the stretches 965 yards from the place of treatment. In the other three experiments the maximum effects were obtained in the remotest stretches, and this result is especially emphasised in Expt. C.2, where at 252 and 540 yard distances there was no definite effect within 24 hours, and only 60 per cent. reduction on the second day, although there were considerable kills at distances of 965 yards and beyond.

(iii) There is some evidence that the larvicidal effect persisted for a longer time at the places furthest from the point of treatment (Expts. C.3, C.4). This might have been because the DDT finished its passage through these places at a later time (*see* below).

(iv) Although the examined stretches were at various angles in relation to the current—some on straight lengths of bank, others on the inside of curves—there was no evidence of any marked difference in effectiveness attributable to these differences. Such a difference would not have been unexpected.

(v) Survival of two pupae, and only one larva, after Expt. C.4, despite the very small proportion of pupae normally found, indicates that pupae are much less affected by DDT than larvae.

TABLE IV.

Percentage survival of Larvae and Pupae after treatment of a river (Experiment C)

Dose, 5% DDT in oil	Time after treatment	Untreated control	Average distance from point of treatment					
			105 yds.	252 yds.	540 yds.	965 yds.	1400 yds.	2150 yds.
C. 1 1 pint	2 days	107%	63%	52%	60%	18%	21%	34%
	3 days	70%	63%	18%	76%	19%	39%	97%
C. 2 2 quarts	1 day	288%	175%	93%	100%	19%	26%	12%
	2 days	103%	175%	34%	38%	Nil	31%	3%
	3 days	116%	150%	20%	50%	38%	49%	12%
C. 3 2 gallons... ...	1 day	155%		Nil	Nil	Nil	Nil	Nil
	2 days	80%		Nil	Nil	Nil	Nil	Nil
	3 days	195%		5%	94%	41%	Nil	Nil
	4 days	400%		10%	144%	12%	54%	166%
C. 4 2 gallons... ...	1 day	121%	10%	5%	Nil	Nil	Nil	9%
	2 days	152%	Nil	10%	Nil	Nil	Nil	Nil
	3 days	136%	20%	5%	22%	8%	Nil	Nil
	4 days	170%	10%	14%	122%	Nil	Nil	33%

Spread of the Oil Film.

A two gallon dose was applied to the river, and the progress of the resultant oil film was observed. These observations were not easy to make because the thinnest visible films are very difficult to see, unless the lighting and direction of viewing are exactly right; breaks in such films are sometimes the only means of detecting their presence. Moreover very thin oil films are not visible, and it is possible that such films may still be partially or completely lethal, if they act for a sufficient time.

One hundred yards below the point of application the film was thick and unbroken for 6 minutes. Small breaks formed by uprising eddies of water then began to appear; after 10 minutes these breaks covered about one-third of the surface, and the oil film was noticeably irregular in thickness. Twelve minutes after arrival the film covered about half of the surface. Then the film became gradually thinner, and it spread out again until it once more covered most of the surface. At the same time it became less readily visible, and the last time at which it could be detected was one hour after the arrival of the film.

The film was never very thick 1,380 yards downstream, but it persisted much longer. It arrived one hour after the time of treatment, and for two hours most of the surface was covered by an easily visible film. The film then gradually became thinner, but careful examination showed that it persisted for more than six hours. Occasional small wisps of oil were visible after 8½ hours.

The longer persistence of the film at the greater distance from the treatment point explains the higher larval kill there, and indicates that weak doses acting over long periods are more effective than strong doses acting over proportionally shorter times. The results obtained in Expt. A indicated that this effect was considerably more marked among Culicines than among Anophelines, probably because the former only came into contact with the film intermittently and stood more chance of evading contact with the quicker-passing film.

The film persisted longest in eddies and backwaters, wherever the flow was slowed down by either obstructions or vegetation. Seventy-five yards downstream there was a small eddy caused by a débris-festooned tree stump. The obstruction was about four feet away from the bank, and 18 ins. wide. The eddy was insufficient to hold back any floating débris, but the oil film persisted here for 80 minutes, although it had disappeared from the unobstructed river 25 yards further down 20 minutes earlier. The retention of the oil in eddies and slowly flowing portions of the stream is of great importance, because *A. minimus* breeds in the weed-covered edges where the stream is slowest. Records from the Desoi River indicated that the rate of flow through its grassy edge was less than one-thirtieth of the rate in midstream (Thomson, 1940).

The lethal effect of DDT on still water (Ribbands, 1945) was found to be so marked that I then suggested that possibly DDT was lethal in a monomolecular film of oil. Professor N. K. Adam has kindly calculated for me that with a dose of one-fifth pint of 5 per cent. DDT in oil per acre (which was markedly lethal in these tests) the DDT film would be 1-2 monolayers thick, if evenly spread. At this dose the oil film would be 282 Angström units thick, if evenly spread, and this probably corresponds to about 20 molecular layers. Hence the widely spreading lethal effects of doses of DDT in oil are probably due to the spreading of very thin multimolecular films of oil, which contain approximately a monolayer of DDT.

Residual Effects of DDT.

The absence of larvae from the river for two days after heavy treatment with DDT in oil is not attributed to a residual effect, but to lethal effects on any eggs present at the time of treatment. Either the DDT in oil was lethal to the eggs themselves or it clung to them and killed all larvae emerging from them. The mosquito population returned rapidly to normal from the third day onwards, and pupae of both *A. minimus* and *A. varuna* were obtained from treated stretches iii-iv on the eighth day after treatment.

Buxton (1945 *b*) has shown that on still waters, where the DDT is not carried away, complete kill is frequently followed by a period of partial irregular control, and my results (Ribbands, 1945) have shown that whereas the residual larvicidal effects of waste oil terminated abruptly, yet mosquito populations treated with DDT sometimes remained subnormal for a long period after complete kill had ceased to be attained. Both these results fit an hypothesis made by Colonel J. W. Scharff,

that when the DDT has ceased to be immediately effective it may still remain in quantities sufficient to poison the larvae gradually, so that most might survive their first instar but succumb in later instars. Such an effect would be scientifically interesting but would not be of practical use unless it were found to be consistent as well as prolonged, because malaria control must be very largely dependent on unskilled and inexact methods, and the time and skill required to determine the varying duration of the effect might be more costly than a second treatment.

Conclusions.

1. DDT in oil solution, when poured on to streams and allowed to drift downstream, was an effective larvicide; 20 c.c. of 5 per cent. DDT eliminated Anophelines from a 300 yards length of 2 ft. wide ditch flowing at up to 50 ft. per minute, and 2 gallons of 5 per cent. DDT was effective through 2,280 yards of a 30 ft. wide river flowing at 75 ft. per minute.

2. The maximum larvicidal effect was exerted a considerable distance below the point of application. The river treatment was considerably more effective 1,000-2,280 yards downstream than it was between 100 and 660 yards. This result was associated with the fact that the oil film took much longer to pass through the more distal portion.

3. This result suggests that the DDT might have been used more economically if the oil film had been spread out at the beginning of its journey downstream, by applying the treatment either just above a partial boom, or through a coarse drip can, or in fractions at intervals.

4. The required dose of 5 per cent. DDT per acre of water surface was 1 pint in Expt. A, $1\frac{1}{2}$ pints in Expt. B, and $3\frac{1}{4}$ pints in Expt. C, but the necessary dose for treatment of flowing waters cannot be expressed adequately in terms of quantity per acre. The dose varies with the width and length of the stream, its rate of flow, and with the quantity of vegetation which impedes that flow at the breeding places, because the lethality of the film is dependent upon the time through which it can act as well as upon the quantity of DDT which it contains.

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EUPHORINE PARASITES OF CAPSID AND LYGAEID BUGS IN UGANDA (HYMENOPTERA, BRACONIDAE)

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In the following pages an attempt is made to deal systematically with a number of Braconids belonging to the subfamily Euphorinae and reared by Dr. T. H. C. Taylor in the course of his investigation into the biology of the Capsid pests of cotton in Uganda. Taylor himself has discussed elsewhere (1945) the importance of the rôle that some of these Braconid parasites are likely to play in the control of their hosts.

To get a better idea of the relationships between the species, I have studied material from other parts of Africa and included descriptions of two new species from Cape Province. In all, ten new species of Euphorinae are described, and they are distributed in two genera.

My work on the collection made by Taylor was made easier for me because he had already, while in Uganda, worked through it and sorted it out into species. Credit is due to him for having discovered a valuable diagnostic character in the structure of the first abdominal tergite of *Euphorus*. I have found it very important for separating species-groups in this genus.

A list of the known African species which I have been unable to recognize from the literature is given at the end of the paper.

The types of all new species are in the British Museum (Natural History).

Subfamily Euphorinae.

With the exception of a single new species, which I place provisionally in *Euphoriella*, Ashmead, all the species included in this paper seen to come within the limits of the genus *Euphorus*, Nees, as defined at the present time (Muesebeck, 1936). In the sense in which I have interpreted them, these two genera may be separated as follows:—

Radius complete throughout; cubitus and intercubitus present, though sometimes in part incomplete. (Head completely unmargined above; ovipositor of the female short, downcurved, concealed) ... ... *Euphorus*, Nees

Radius incomplete; cubitus and intercubitus wanting *Euphoriella*, Ashmead

Key to the African Species of *Euphorus*, Nees (♀♀).

1. Hind wing without a closed submediellan cell. (Sp. appearing pale to the naked eye; notaulices completely wanting; recurrens and 2nd discoidal cell obliterated) ... ... *lamius*, sp.n.

   Hind wing with a closed submediellan cell 2

2. Notaulices completely wanting. (Spp. with the eyes large, obliquely placed and strongly convergent; median cell of the fore wing without hairs; recurrens very short, indistinct, received into the 1st cubital cell widely distant from the intercubitus; sides of the petiole not fused at base beneath) 3

   Notaulices sharply defined throughout, except in one species which has a yellow head and the petiole very strongly widened to apex 6

3. Head and greater part of the thorax pale to the naked eye, being more or less yellowish brown with the head usually more yellowish in tint than the thorax ... *choaspes*, sp.n.
- Entire body dark brown to blackish 4
4. Antenna with 17-18 segments; shortest distance between the eyes on the face only very slightly less than the longer diameter of one of them; face dark brown ... ... *carcinus*, sp.n.
- Antenna with 15 segments; shortest distance between the eyes on the face at most very slightly more than the longer diameter of one of them; face yellowish... 5
5. Shortest distance between the eyes slightly more than one half the longer diameter of one of them; antennae darkened distally ... ... *ariomedes*, sp.n.
- Shortest distance between the eyes about one-third the longer diameter of one of them; antennae yellowish throughout ... ... *daicles*, sp.n.
6. At least the head entirely or almost entirely yellow or fulvous yellow 7
- Entire body black or blackish 8
7. Petiole very long, hardly widened to apex, its sides fused beneath for fully two-thirds its length; thorax darkened only above; 1st abscissa of the radius well defined; notaulices sharply defined throughout ... ... *meriones*, sp.n.
- Petiole short, strongly widened to apex, its sides not fused beneath at base; thorax darkened throughout; 1st abscissa of the radius not defined; notaulices feeble, rarely distinct to as far as middle ... ... *prosper*, sp.n.
8. Claws pectinate (fig. 18). (Antenna with 25-27 segments; front tarsus 3 hardly longer than wide)... *sahlbergellae*, Wilkn.
- Claws not pectinate 9
9. Sides of the petiole not fused beneath at base; temples with a pale oblong patch against each eye; 1st discoidal cell stalked ... ... *praetor*, sp.n.
Sides of the petiole fused beneath over about basal half; temples without a pale patch; 1st discoidal cell not stalked 10
10. Antenna with 25-28 segments; segment 3 of the front tarsus about twice as long as apically wide; flagellum not at all thickened towards apex ... ... *anates*, sp.n.
- Antenna with 17-22 segments; flagellum distinctly thickened towards apex; segment 3 of the front tarsus not longer than apically wide 11
11. Face dark brown but not contrasting conspicuously with the black head ... ... *nigricarpus*, Szépligeti
- Face pale brown or brownish yellow, contrasting conspicuously with the black head ... ... *rhesus*, sp.n.

Euphorus lamius, sp. n.

♂ ♀. Head, thorax (except propodeal and scutellar regions, which are darkened but less so in males than in females), petiole and about basal half of gaster, fulvous; frequently the face, clypeus and basal half of the gaster are more yellowish in tint than the other pale parts of the body. Except that the hind femora and hind tibiae are slightly less bright, the legs are pale fulvous yellow throughout. Fore wings sometimes faintly darkened beyond the basalis (more especially in males) but with a pale streak or diffused cloud cutting the wing at the base of the stigma.

♀. *Head* subcubical, seen from above. Eyes large, very obliquely placed but in a lateral view of the head not obscuring the line of the face; strongly convergent below, the shortest distance between them on the face slightly greater than half the longer diameter of an eye, 7:13. Frons and vertex smooth and unsculptured. Pubescence of the face pale and not particularly dense. Antenna 15-segmented (7 exs.). Maxillary palpi very short. Ocelli in a triangle which is very nearly equilateral. *Thorax*: Mesonotum highly polished, without a trace of notaulices and unsculptured; its hairs fairly numerous when the thorax is seen a little from in front, but otherwise so short and fine as to be not readily visible. Propodeum very finely and superficially rugose reticulate, somewhat dull looking. Mesopleura strongly shining and for the most part smooth; the furrow represented by a very feebly rugulose impression. *Legs*: Spurs of the hind tibia very short, the inner one only $\frac{1}{6}$ as long as the basal segment of the hind tarsus; hairs of the upper surface of the hind tibia extremely short and hardly outstanding when the tibia is seen from the side; apical segment of the front and middle tarsus not noticeably enlarged. *Wings*: Recurrens and 2nd discoidal cell obliterated; median cell with a few inconspicuous hairs on its lower side; basalis a little thickened; radial cell very short; submediellan cell of the hind wing not closed (fig. 7). *Abdomen*: Petiole about $2\frac{1}{2}$ times as long as wide, more or less parallel-sided, fairly smoothly striated; the spiracles are rather prominent and the basal pits deep and rather conspicuous; sides of the petiole widely separated at base beneath.

♂. Antenna with 16 segments (4 exs.). Eyes smaller than in the female, the shortest distance between them on the face being almost equal to their longer diameter, 8:9.

Length: ♂ ♀, 1·9 mm. approx.

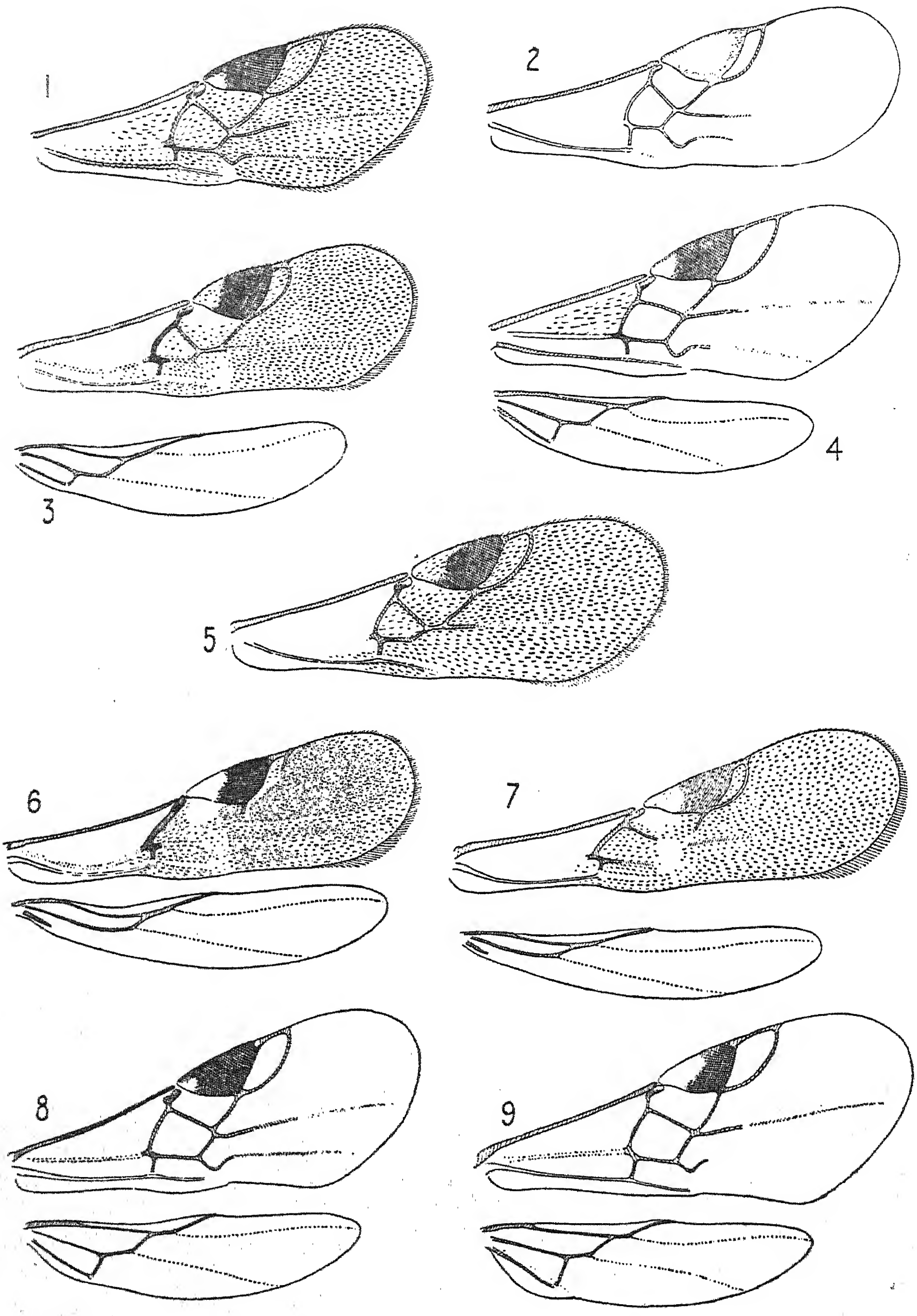
Uganda: Kawanda, 22nd-23rd March, 1943, 2 ♂♂, 2 ♀♀; March, 1943, 2 ♂♂, 3 ♀♀ (one female the type), all ex nymphs of *Engytatus* on *Gynandropsis* (*T. H. C. Taylor*). All specimens bear the serial number " T.959 ".

This species differs from all the other species of *Euphorus* described in this paper by the shortness of the hind tibial spurs and the extent to which the venation of the fore wing is incomplete.

Euphorus carcinus, sp. n.

♂ ♀. Blackish with the legs considerably darkened, the hind pair infuscated virtually throughout; face dark brownish. Basal 4-5 segments of the antenna pale, the rest blackish. Stigma pale on about basal quarter.

♀. *Head* somewhat cubical, seen from above. Eyes large, obliquely placed, their longer axis, when the head is seen from the side, forming an angle of about 30 degrees with a line joining a posterior ocellus and the anterior corner of the base of the mandible (fig. 11); strongly convergent, the shortest distance between them on the face being slightly less than their longer diameter, 4:5; further, in a lateral view of the head, the eye leaves completely free the line of the face. Frons and vertex highly polished, virtually unsculptured. Pubescence of the face decidedly thin and comparatively inconspicuous. Ocelli in a triangle with base much longer than sides. Antenna short, a little thickened towards apex, with



FIGS. 1–9.—(1) *Euphorus anates*, sp. n., ♀, fore wing; (2) *E. prosper*, sp. n., ♀, fore wing; (3) *E. ariomedes*, sp. n., ♀, wings; (4) *E. meriones*, sp. n., ♀, wings; (5) *E. carcinus*, sp. n., ♀, fore wings; (6) *Euphoriella marica*, sp. n., wings; (7) *Euphorus lamius*, sp. n., ♀, wings; (8) *E. nigricarpus*, Szépligeti, ♀, wings; (9) *E. praetor*, sp. n., ♀, wings.

17-18 segments; 17(5), 18(1). Maxillary palpi long and well developed (fig. 30). *Thorax*: Mesonotum highly polished, without a trace of notaulices and virtually without hairs even around the anterior declivous parts. Sides of the pronotum strongly shining and with only very little sculpture. Disc of the mesopleura and depressed part beneath the wing insertions polished and virtually unsculptured; furrow represented by a small, rather feebly rugose or costate area of ill defined limits. Propodeum with rather fine, very irregular reticulation; anterior dorsal areas not sharply delimited, their surface tending to be quite smooth. Hairs of the upper surface of the hind tibia very sparse and when the tibia is seen from the side, the hairs along its dorsal edge virtually not outstanding; longer spur of the hind tibia clearly a little less than half the length of the basal segment of the hind tarsus; apical segment of the front and middle tarsus not noticeably enlarged. Wings: Radial cell very short, measured along wing edge about $\frac{1}{4}$ as long as stigma; recurrens very short, received into the 1st cubital cell; basalis slightly thickened but not darkened; 1st cubital cell evenly hairy all over; median cell without hairs both above and below; 2nd discoidal cell not delimited distally (fig. 5). *Abdomen*: Petiole about $2\frac{1}{2}$ times, rarely almost 3 times, as long as apically wide and about $1\frac{1}{2}$ times as wide at apex as at base; smoothly striated, in profile only very feebly curved; its sides beneath widely separated (fig. 33).

♂. Antenna 18-19 segmented; 18(6), 19(1). Shortest distance between the eyes on the face slightly shorter than their longer diameter, 11:12. Head, seen from above, slightly less subcubical than in the female. Parameres of the genitalia as in figures 37 and 43; apical lobes of the aedeagus with a cluster of about six fine spines at tip (fig. 36); volsellar plate and digitus as in fig. 38.

Length: ♂ ♀, 2·1-2·3 mm.

Uganda: Kawanda, 6 ♀♀ (one the type), 7 ♂♂, bred March-April, 1943, from nymphs of *Nysius binotatus*, Germ. (Lygaeidae) on *Erigeron* and *Vernonia* (*T. H. C. Taylor*). All specimens bear the serial number " T.957 ".

According to Taylor, this species develops singly in its host and spends 16-20 days in the cocoon. It is worthy of note, too, that *carcinus* provides the only known case, so far as I am aware, of *Euphorus* parasitising a Lygaeid bug.

Euphorus ariomedes, sp. n.

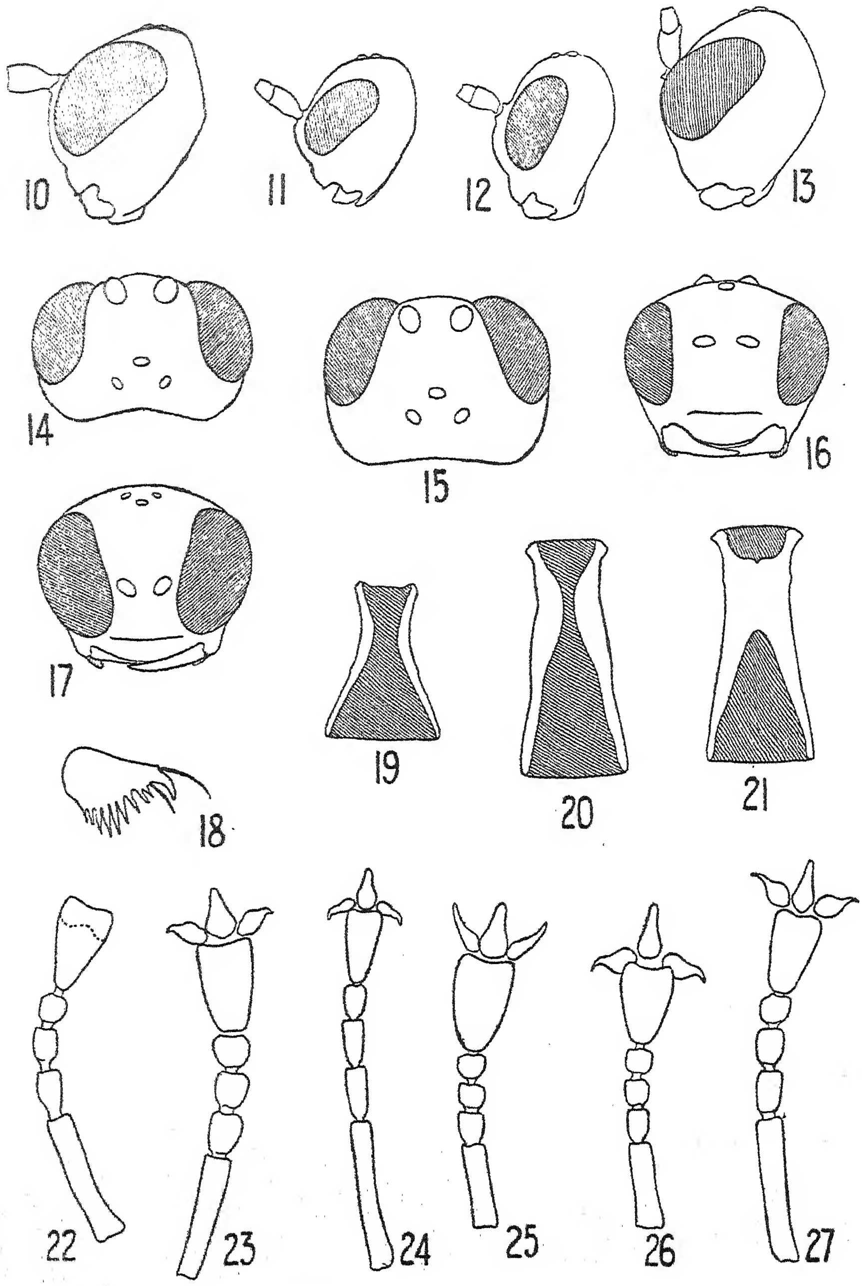
Very closely related to *carcinus* from which it differs as follows:—

♀. On the whole a considerably paler species, the general colour being dark brownish rather than blackish; the face and clypeus are entirely bright yellowish. Antennae paler, about proximal half to two-thirds being yellowish. Eyes in eight out of nine females blue-green in death.

♀. *Head* slightly more cubical seen from above. Eyes larger, slightly more obliquely placed, appearing more convex below and decidedly more convergent, the shortest distance between them on the face being a little more than half the longer diameter of one of them, 9:16; in a lateral view of the head, the eye only just leaves exposed the line of the face (cf. fig. 11). Antenna with 15 segments (8 exs.). Maxillary palpi much shorter and, by comparison with those of *carcinus*, feebly developed (fig. 31). Radial cell shorter, more rounded at its distal extremity; basalis conspicuously thickened and darkened; hairs virtually absent from the upper half of the 1st cubital cell (fig. 3).

♂. Differs from the male of *carcinus* in being paler in colour, the face being entirely pale yellowish; the eyes are larger, the shortest distance between them being about two-thirds the longer diameter of one of them, 11:15. Antenna with 17-18 segments, 17(2), 18(4); flagellum thicker, the segments, more especially the proximal ones, less elongate. Apical lobes of the aedeagus with minute teeth (fig. 40); dorsal margin of parameres without a tooth opposite the digitus.

Length: ♂ ♀, 1·9-2·3 mm.



FIGS. 10–27.—(10) *Euphorus nigricarpus*, Szépligeti, ♀, head (lateral); (11) *E. carcinus*, sp. n., ♀, head (lateral); (12) *E. praetor*, sp. n., ♀, head (lateral); (13) *E. meriones*, sp. n., ♀, head (lateral); (14) *E. nigricarpus*, Szépligeti, ♀, head (from above); (15) *E. meriones*, sp. n., ♀, head (from above); (16) *E. praetor*, sp. n., ♀, head (from in front); (17) *E. rhesus*, sp. n., ♀, head (from in front); (18) *E. sahlbergellae*, Wilkinson, ♀, front claw; (19) *E. prosper*, sp. n., ♀, petiole (ventral); (20) *E. praetor*, sp. n., ♀, petiole (ventral); (21) *E. nigricarpus*, Szépligeti, ♀, petiole (ventral); (22) *E. sahlbergellae*, Wilkinson, ♀, front tarsus; (23) *E. praetor*, sp. n., ♀, front tarsus; (24) *E. anates*, sp. n., ♀, front tarsus; (25) *E. meriones*, sp. n., ♀, front tarsus; (26) *E. rhesus*, sp. n., ♀, front tarsus; (27) *E. nigricarpus*, Szépligeti, ♀, front tarsus.

Uganda: Serere, November, 1942, 7 ♀♀ (one the type), 3 ♂♂, bred from *Lygus* sp. D. on *Erigeron;* Kawanda, 7th-9th November, 1943, 2 ♂♂, ex *Lygus* sp. D. on *Erigeron*, 23rd February, 1943, 1 ♂, December, 1943, 1 ♂, both ex nymphs of *Lygus* sp. T. on *Basella* (*T. H. C. Taylor*). All specimens bear the serial number " T. 866 ".

The details of the wing venation and the yellowish face provide the most readily appreciated differences between this species and *carcinus*. Greater care is needed to distinguish *ariomedes* from the following species to which it is more closely related than to *carcinus*.

Euphorus daicles, sp. n.

May be compared with *carcinus* as follows:—

♀. Head brown with the face and clypeus more or less yellowish. Antennae yellowish throughout. Hind femora, and the hind tibiae towards apex, very feebly infuscated.

Head more cubical seen from above (more cubical even than that of *ariomedes*). Face quite densely clothed with whitish pubescence. Eyes larger, much more convergent below, where the shortest distance between them is only about one third the longer diameter of one of them, 6:17 (more convergent than in *ariomedes*); further, in a lateral view of the head, the eye just obscures the line of the face. Ocelli virtually in an equilateral triangle. Antenna much shorter, 15-segmented (3 exs.). Maxillary palpi much less well developed, the antepenultimate segment much shorter; this segment is considerably shorter also than in *ariomedes* (cf. fig. 31). Basalis distinctly thicker but not so much darkened as in *ariomedes*; recurrens and discoideus virtually obliterated so that the limits of the 2nd discoidal cell are not defined; 1st cubital cell distinctly less hairy towards stigma.

Length: ♀, 2 mm. approx.

Uganda: Kawanda, September, 1943, 3 ♀♀, bred from Capsid nymphs (probably *Stenotus*) from flowers of Elephant grass (*Pennisetum*) (*T. H. C. Taylor*). All specimens bear the serial number " T. 1073 ".

Characteristic of this little species are the entirely pale antennae and the strongly convergent eyes. No other species described in this paper has them so close together on the face.

Euphorus choaspes, sp. n.

May be compared with *carcinus* as follows:—

♀♂. Differs strikingly in colour, being a predominantly pale marked species. Head, thorax, except the propodeal and scutellar regions which are darkened, fulvous; abdomen on the whole dark brownish but tergite (2+3) sometimes a little paler. Hind coxae pale; hind femora rarely a little infuscated. Stigma colourless on almost basal third.

♀. *Head,* seen from above, more subcubical. Eyes larger, more obliquely placed, more convergent below, the shortest distance between them on the face being slightly greater than half the longer diameter of one of them, 8:15. Antenna 15-segmented (3 exs.); segment 1 of the flagellum shorter, about twice as long as wide at apex. Maxillary palpi less well developed. Notaulices absent in three out of four females but in the fourth (Aliwal North) an ill-defined row of punctures marks their anterior origin, extending to middle of disc; in this female, too, an elongate area of faint striation occurs on each side of the middle line on posterior half of mesonotum. Inner spur of the hind tibia shorter, about one-third as long as the basal segment of the hind tarsus. Hairs of the fore wing more numerous but paler and hard to see; recurrens and discoidalis obliterated; hence the 2nd discoidal cell not defined.

♂. Eyes smaller than in the female, the shortest distance between them on the face nearly equal to the longer diameter of one of them, 5:6. Antennae appearing entirely yellow, only the apical 3-4 segments being faintly darkened. Genitalia (fig. 46).

Length: ♂ ♀, 2 mm. approx.

Cape Province: Aliwal North, 4,350 ft., 1st-13th January, 1923, 3 ♀♀ (one the type), 2 ♂♂; Ceres, November, 1920, 1 ♂. Natal: Van Reenen, Drakensberg, 1st-22nd January, 1927, 1 ♀ (*R. E. Turner*).

In the degree to which the eyes converge on the face, and in the number of antennal segment, this species resembles *ariomedes* much more closely than *carcinus*. It differs from the former species, however, in colour, in having the venation more reduced and in having the 1st segment of the flagellum shorter and the longer spur of the hind tibia shorter.

Euphorus meriones, sp. n.

♂ ♀. In far greater part brownish yellow, the species being conspicuously pale marked to the naked eye. Head entirely pale brownish yellow, except for the ocellar triangle and a small area in front of, and adjacent to, it; thorax blackish above; the mesonotum usually entirely dark as in the type female but sometimes pale on anterior half; thorax, otherwise, entirely pale; petiole blackish throughout; gaster becoming dark in about apical two-thirds. Legs pale yellowish, except that the hind tibiae become dark towards the apical third. Stigma with a pale cloud on about apical quarter.

♀. *Head*, seen from above, almost cubical (fig. 15). Eyes large, obliquely placed, strongly convergent below, the shortest distance between them on the face being about two-thirds the longer diameter of one of them, 11:18; seen from the side, the eye is decidedly bulging below and breaks the line of the face (fig. 13). Antenna with 19 segments; flagellum 1 and 2 decidedly slender; 1, more especially, very shining and clothed only with short, rather sparse, outstanding hairs (fig. 35). Frons very shining but with a certain amount of vague punctate-rugosity. Pubescence of the face yellowish, not particularly dense. Ocelli in a triangle with base clearly longer than sides. *Thorax*: Mesonotum highly shining, bare except for inconspicuous hairs around its anterior declivous part; surface of lobes with remote ill-defined punctures or puncture-like impressions; notaulices strongly foveolate throughout. Sides of the pronotum with very irregular punctate-reticulation all over. Mesopleura without a clearly defined furrow, this being represented by an elongate area of rugosity which may be reduced to a few large fovea arranged more or less in a row as in the type. Propodeum not obviously convex, forming only a very feeble curve in profile; its surface covered all over with shining, irregular reticulation. Apical segment of the front tarsus very greatly enlarged (fig. 25); upper edge of the hind tibia, when seen from the side, with short outstanding hairs; longer spur of the hind tibia slightly less than half the length of the basal segment of the hind tarsus. Wings: 2nd discoidal cell very distinctly stalked; numerous setae over almost the entire surface of the median cell (fig. 4). *Abdomen*: Petiole decidedly long and narrow, not wider at apex than at base, in profile roundly elbowed just distal to middle (fig. 32); its surface smooth-looking and with only traces of widely spaced striation; its sides fused beneath for fully two-thirds its length.

♂. Head less cubical than in the female. Eyes considerably smaller, the shortest distance between them only very slightly less than their longer diameter; when the head is seen from the side, the eye leaves freely exposed the line of

the face. Antenna with 19-20 segments (7 exs.); flagellum slightly more slender than in the female, the segments more elongate. Genitalia (fig. 41); right paramere (fig. 39).

Length: ♂ ♀, 3·6 mm. approx.

Uganda: Kawanda, December, 1943, 6 ♂♂, 2 ♀♀ (one the type), 30th March. 1943, 1 ♂, bred from *Lygus* sp. T. on *Basella* (*T. H. C. Taylor*). All specimens bear the serial number "T.967".

Taylor thinks this may be a forest species only. He states that the period spent in the cocoon is 15-16 days. Taxonomically, the insect is very distinctive on colour alone; this, in combination with the slender proximal segments of the flagellum, swollen apical segment of the front tarsus and the long slender petiole sums up what seems to be most characteristic about the species and will separate it easily from the other species with complete notaulices. On the structure of the petiole, it probably belongs to a species-group not otherwise represented among the species discussed in this paper.

Euphorus prosper, sp. n.

♂ ♀. Dark brown with the head, antennae and legs fulvous yellow. Wings faintly yellowish; stigma pale with a faintly darker border (fig. 2).

♀. *Head* not markedly subquadrate. Eyes large, obliquely placed and strongly convergent below, the shortest distance between them being slightly more than half the longer diameter of one of them, 9:17; in a lateral view of the head, the eye almost obscures the line of the face. Pubescence of the face whitish, rather long, moderately dense. Frons and vertex shining and with a few very feebly indicated punctures. Ocelli in a triangle with base clearly a little longer than sides. Antenna with 15 segments (6 exs.), shorter than head and thorax together; flagellum clearly a little thickened towards apex, the more apical segments slightly longer than wide. *Thorax*: Mesonotum strongly shining, at first sight virtually bare but with sparse, inconspicuous hairs around the anterior declivity; notaulices usually faintly indicated to about middle of disc, more rarely indicated to as far as the posterior margin of the mesonotum by a line of very feeble foveae which posteriorly become progressively smaller and more widely spaced; in some examples the posterior course of the notaulices is faintly indicated by a smooth impressed line. Sides of the pronotum somewhat dull-looking, closely rugose-reticulate. Mesopleura with some sort of confused but not strong sculpture virtually everywhere; the furrow not defined, its limits obscured by a large area of rugosity. Propodeum very closely rugose-reticulate all over. Apical segment of the front tarsus rather large and swollen; hairs of the upper surface of the hind tibia very sparse and virtually not outstanding when the tibia is seen from the side; longer spur of the hind tibia one-third as long as the basal segment of the hind tarsus. *Abdomen*: Almost not petiolate, the petiole strongly widened to apex, only very slightly longer than its apical width, 13:11, its surface almost flat, very finely and closely striated; sides of the petiole widely separated at base beneath (fig. 19).

♂. Antenna with 17 segments (1 ex.). Shortest distance between the eyes on the face almost equal to the longer diameter of an eye, 12:13. Genitalia (fig. 44).

Length: ♂ ♀, 1·9-2 mm.

Cape Province: Cape Peninsula, Camps Bay, 1st-20th October, 1920, 7 ♀♀ (one the type), 1 ♂ (*R. E. Turner*).

This is a most distinctive little species and is chiefly characterised by the sculptured mesopleura, the colour of the stigma and the shape of the petiole.

Euphorus sahlbergellae, Wilkinson.

Euphorus sahlbergellae, Wilkn., 1927, Bull. ent. Res., **17**, p. 309.

♀. Black. Pronotum with a reddish brown flush around the anterior margin. Hind femora and hind tibiae (except the extreme base of the latter which is pale) infuscated. Antennae brownish yellow on fully basal half. Wings slightly smoky; stigma pale only at extreme base.

Head strongly transverse, of simple form. Eyes moderately large, clearly obliquely placed; shortest distance between them on the face a little shorter than the longer diameter of one of them, 19:22. Ocelli in a triangle with base almost twice as long as sides. Antenna filiform, with 25-27 segments: 25(3), 26(3), 27(1). Face feebly convex; in a lateral view of the head, the eyes just leave free the line of the face; pubescence of the face pale brownish, fairly dense. *Thorax*: Mesonotum almost truncate in front, with rather prominent "shoulders"; its lobes highly polished and virtually bare; no trace of punctation; notaulices deep, complete, foveate. Sides of the pronotum very shining and at least on lower half with much coarse rugosity. Disc of the mesopleura on the whole shining and unsculptured, divided obliquely by a (sometimes ill-defined) foveate furrow. Propodeum with coarse shining rugose reticulation all over. Legs: apical segment of the anterior tarsus large and swollen, its claws, as well as those of the other legs, pectinate (figs. 18 & 22); inner spur of the hind tibia about one-third as long as the basal segment of the hind tarsus. Wings as in *anates* sp. n. (cf. fig. 1); median cell appearing quite bare on its upper surface but showing on examination 3-6 hairs distally. *Abdomen*: Petiole from twice to two-and-a-half times as long as apically wide, its striation rather widely spaced and often decidedly obsolescent; sides of the petiole fused beneath to just beyond middle.

♂. Face decidedly brownish in tint. Antenna more slender than in the female, pale virtually throughout and with 25 segments (3 exs.). Eyes smaller than in the female, the shortest distance between them distinctly a little greater than the longer diameter of one of them. Apical segment of the front tarsus not quite so swollen in proportion to the preceding segments; claws without the obvious pectinations of the female.

Length: ♂ ♀, 3-4 mm.

Gold Coast: East Province, Asamankese, 1926 and 1929, 8 ♀♀, 3 ♂♂, ex *Sahlbergella singularis*, Hagl., a pest of cacao. Nigeria, Awana, 1943, 1 ♀, ex *S. singularis*, Hagl. Tafo, 1 ♂, bred 8th April, 1943, from 4th instar nymph of *Boxia khayae*, China (Capsidae) on *Khaya grandifoliola* (*H. E. Box*).

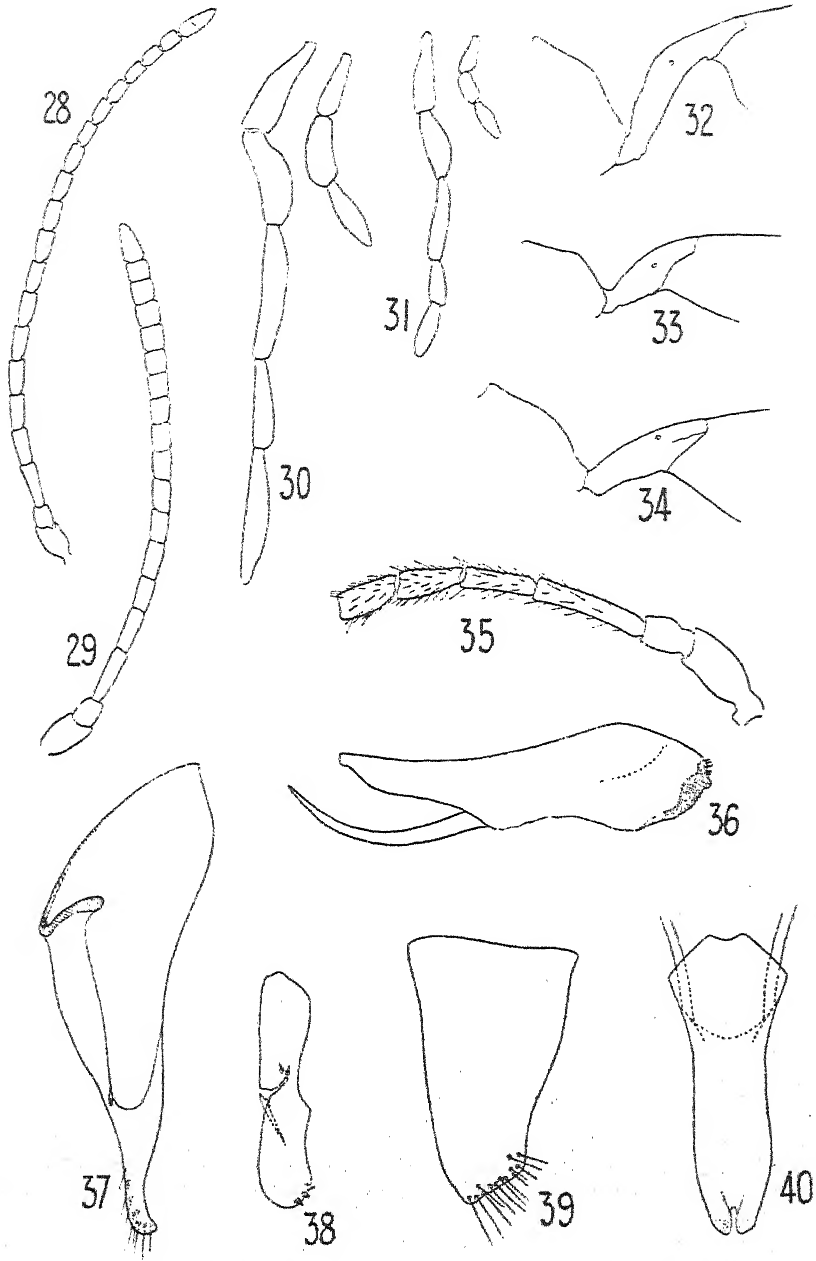
The male of *sahlbergellae* could easily be confused with that of *anates* sp. n. for the character which separates at once the females of these two species, namely, the pectinate claws of *sahlbergellae*, does not hold for the males. The wings of the male of *sahlbergellae* are certainly a little darker than those of *anates* but more useful criteria of difference are the much smaller number of hairs on the distal part of the median cell of *sahlbergellae* and the greater length of the apical segment of the front tarsus in proportion to the three preceding segments together in the last mentioned species.

Mr. H. E. Box has informed me that *Euphorus sahlbergellae* is also a parasite of *Bryocoropsis laticollis*, Schum., on cacao as well as of *Sahlbergella singularis*, Hagl., and that in these hosts it is hyperparasitised by the Ichneumonid, *Mesochorus melanothorax*, Wilkinson. (*See* also discussion of *E. anates* sp.n.)

Euphorus nigricarpus, Szépligeti.

Euphorus nigricarpus, Szép., 1913, Ann. hist.-nat. Mus. hung., **2**, p. 607.

♂ ♀. Black; face sometimes very faintly brownish. Flagellum sometimes yellowish on about basal half; sometimes dark throughout. Stigma with an ill-delimited pale cloud at extreme base. Hind femora to a greater or less degree infuscated throughout; when darkest, they are in sharp contrast with the yellowish middle femora.



FIGS. 28–40.—(28) *Euphorus praetor*, sp. n., ♀, antenna; (29) *E. nigricarpus*, Szépligeti, ♀, antenna; (30) *E. carcinus*, sp. n., ♀, palpi (same scale as fig. 31); (31) *E. ariomedes*, sp. n., ♀, palpi (same scale as fig. 30); (32) *E. meriones*, sp. n., ♀, petiole (lateral); (33) *E. carcinus*, sp. n., ♀, petiole (lateral); (34) *E. praetor*, sp. n., ♀, petiole (lateral); (35) *E. meriones*, sp. n., ♀, first six antennal segments; (36) *E. carcinus*, sp. n., ♂, aedeagus (lateral); (37) *E. carcinus*, sp. n., ♂, right paramere; (38) *E. carcinus*, sp. n., ♂, volsellar plate and digitus; (39) *E. meriones*, sp. n., ♂, right paramere; (40) *E. ariomedes*, sp. n., ♂, aedeagus (dorsal).

♀. *Head* strongly transverse and of simple form (figs. 10 and 14); frons and vertex polished and virtually unsculptured; pubescence of the face pale, dense and even. Eyes large, strongly convergent below, the shortest distance between them (on the face) two-thirds the longer diameter of one of them, 11:17. Antenna with 17-22 segments: 17(2), 18(8), 19(5), 20(1), 21(1), 22(1); flagellum clearly a little thickened towards apex (fig. 29). Ocelli in a triangle with base much longer than sides. *Thorax*: Mesonotum with fine, inconspicuous hairs around its anterior declivous part but otherwise virtually bare, highly polished and impunctate; notaulices sharply defined, foveolate throughout. Propodeum evenly convex, shining and closely reticulate all over, except for fairly well defined, narrow (in transverse direction) anterior areas which show some feeble punctation. Sides of the pronotum, at least on upper flat part, very shining and with only feeble, smoothed-out rugosities. Mesopleura very shining and on the whole smooth except for the ill-defined furrow which is indicated by an irregular row of feeble foveae or linear area of rugosity. Apical segment of the front tarsus not markedly enlarged (fig. 27); longer spur of the hind tibia a little less than half the length of the basal segment of the hind tarsus; hairs of the upper edge of the hind tibia when this is seen from the side, very short, standing out at about 45 degrees. Wings: 2nd discoidal cell not or hardly stalked; upper surface of the median cell at first sight bare but showing on closer examination about 6 scattered hairs towards apex (fig. 8). *Abdomen*: Petiole only feebly widened towards apex, here about 1½ times as wide as at base, its surface fairly evenly striated; in profile, the petiole is evenly and very weakly curved; its sides fused along middle line to about middle (fig. 21).

♂. Antenna with 19-23 segments: 19(2), 20(3), 21(1), 23(1); flagellum not thickened towards apex, the more apical segments all longer than wide. Eyes less large than in the female and less convergent below, where the shortest distance between them is equal to the longer diameter of one of them. Longer spur of the hind tibia slightly more than half the length of the basal segment of the hind tarsus. Genitalia (fig. 42).

Length: ♂ ♀, 2·2-2·6 mm. (excepting exs. from *Megacoelum*, all of which are ca. 3 mm.).

Uganda: Kawanda, February-March, 1943, 1 ♂, 6 ♀♀, bred from *Lygus* sp. D. on *Erigeron*; October-November, 1942, 2 ♂♂, 1 ♀, ex *Lygus simonyi* on cotton; October, 1942, 1 ♂, swept from cotton; March and June, 1943, 2 ♀♀, ex *Corizidolon* on *Cajanus*; 2nd February, 1943, 1 ♀, ex ? *Corizidolon* on cotton; 28th January, 1943, 1 ,♀ ex nymph of *Deraeocoris* sp. on *Cajanus*; January-February, 1943, 2 ♂♂, 1 ♀, ex nymphs of *Deraeocoris* sp. on cotton; February, 1943, 1 ♀ ex nymph of *Lygus* sp. on *Albizzia*; June, 1943, 1 ♂, 1 ♀, ex nymphs of *Megacoelum* sp. on *Ricinus*; June, 1943, 1 ♀, ex nymph of *Megacoelum* sp. on sorghum; October, 1942, 1 ♀ ex adult of *Megacoelum* sp. (*T. H. C. Taylor*). Kampala, 20th December, 1929, 1 ♀, March, 1930, 1 ♀ both ex *Deraeocoris* sp. (*G. L. R. Hancock*). All specimens bear the serial number " T.801 A ".

The female from the *Lygus* nymph on *Albizzia* differs from typical forms in having the flagellum hardly paler at base and the middle as well as the hind legs dark brown virtually throughout. I regard this specimen as merely a colour variety.

The locality of the type as recorded by Szépligeti is " German East Africa: Arusha-Ju, (Katona) ".

According to Taylor, ***nigricarpus*** normally emerges from large nymphs of its Capsid hosts, but occasionally does so from adults. The larva almost always emerges from its host in the early forenoon, and the adult from the cocoon usually before 9 a.m. The period spent in the cocoon is 14-17 days.

Euphorus rhesus, sp. n.

This species is remarkably like *nigricarpus* but it seems to differ from that species constantly in a few respects; these are:—

♀. Face contrasting brown to pale brownish yellow. Eyes slightly more convergent below, the shortest distance between them on the face being only about one-half the longer diameter of one of them. 10:19 (fig. 17). Apical segment of the front and middle tarsus markedly swollen (fig. 26). Antenna with 17-19 segments: 17(4), 18(8), 19(1). Median cell with numerous colourless, inconspicuous hairs over apical half.

♂. Head behind the eyes as well as the face, entirely fulvous or brownish yellow, the pale colour sometimes faintly indicated around the eye margins above. Frons slightly less polished than that of the male of *nigricarpus*, there being a feeble indication of punctation, more especially towards sides.

Uganda: Kawanda, July, 1943, 18 ♀♀, 11 ♂♂, ex nymphs of *Stenotus* sp. on Elephant grass (*Pennisetum*). Serere, July, 1943, 1 ♂, ex nymph of *Stenotus* sp. on grass (*T. H. C. Taylor*). All specimens bear the serial number " T.801 A ".

Euphorus anates, sp. n.

A species related to *nigricarpus* but differing from it widely as follows:—

♂ ♀. Hind femora not quite so strongly infuscated; hind tibiae infuscated on hardly more than basal half. Face slightly more brownish in comparison with the rest of the head. Antennae yellowish on about basal half.

♀. Eyes less large, less obliquely placed and not markedly convergent below, the shortest distance between them on the face nearly equal to the longer diameter of one of them, 16:19. Antenna longer, not at all thickened towards apex and with 26-28 segments: 26(1), 27(2), 28(2). Sides of the pronotum within the oblique depression strongly and fairly evenly costate. Mesopleura without a clearly defined furrow but the area normally occupied by it deeply pitted with smooth foveae of various sizes, some of them very large. Propodeum more coarsely rugose-reticulate; anterior areas virtually not indicated. Apical segment of the front tarsus less enlarged in proportion to the combined length of the three preceding segments; segment 3 very distinctly longer than wide (fig. 24); inner spur of the hind tibia equal to half the length of the basal segment of the hind tarsus. Upper surface of the median cell with numerous long hairs (about 25) over its more distal surface (fig. 1).

♂. Shortest distance between the eyes on the face slightly greater than the longer diameter of one of them, 6:5.

Length: ♂♀, 2·6-3 mm.

Gold Coast: Tafo, March-April, 1943, 6 ♀♀ (one the type, em. 12. iii), 2 ♂♂ ex nymphs of *Helopeltis* sp. on cacao. Nigeria: 1 ♀, 1 ♂, 1924 (*O. B. Lean*).

The female from Nigeria has the shortest distance between the eyes exactly equal to the longer diameter of one of them. I can find no other difference between it and the females from the Gold Coast and provisionally accept this difference as falling within the range of specific variation.

Whether *anates* is specifically distinct from *helopeltidis*, Ferrière, from Java, I am unable to say. I have examined the type of *helopeltidis* (a male, not a female, as stated by Ferrière) and find it extremely closely related to *anates*. Whereas the male of *anates* has a highly polished mesonotum which gives the impression of being virtually bare and has the mesonotum somewhat truncate in front with rather prominent " shoulders ", the male of *helopeltidis* has this part much less polished, rather thickly hairy all over, the middle lobe quite definitely, though extremely feebly punctate, and no indication of an anterior truncation. It is probable that the problem is one of subspeciation but more data are required before conclusive opinions can be expressed.

As already pointed out in the discussion of *sahlbergellae*, Wilkinson, the male of *anates* could easily be confused with that of Wilkinson's species.

Mr. H. E. Box has informed me that although he has dissected a large number of the early stages of *anates*, he has never found them parasitised by *Mesochorus*.

The specimens from Nigeria are almost certainly part of the material bred by Lean (1926) from *Helopeltis* on cotton and recorded by him as doubtfully *nigricarpus*, Szépligeti.

Euphorus praetor, sp. n.

♀. Black; face usually a little paler than the dark parts of the head; temples with an oblong yellowish brown patch against each eye; clypeus yellowish brown in not very dark specimens but hardly paler in the darkest individuals. Antennae becoming paler towards basal third or less. Legs predominantly yellowish but the hind tibiae at about apical third and the hind tarsi throughout, infuscated. About basal third of the stigma pale.

Head of simple form, strongly transverse (figs. 12 and 16). Eye not very large, vertically placed, its longer axis more or less parallel with a line joining a posterior ocellus and the anterior corner of the base of the mandible; further, seen from in front, the eyes are hardly convergent below, the distance between them on the face exactly equal to the longer diameter of one of them. Antenna rather long and powerful, with 20-24 segments: 20(2), 21(2), 22(3), 23(1), 24(1); flagellum very slightly attenuated towards apex (fig. 28). Ocelli in a triangle with base much longer than sides. Pubescence of the face pale, with faint brownish tinge, fairly dense and even. *Thorax*: Mesonotum bare, except for some inconspicuous hairs around the anterior declivous part; otherwise highly polished and impunctate; notaulices sharply defined throughout, deep, and fairly regularly foveolate. Sides of the pronotum with somewhat superficial rugosities over its middle part. Mesopleura with a long, linear furrow which varies from being fairly evenly costate to feebly rugose throughout; by far the greater part of the disc itself polished and with only feeble traces of sculpture. Propodeum evenly convex, closely rugose reticulate everywhere, except for fairly clearly defined narrow (in transverse direction) anterior areas which show some feeble punctation. Apical segment of the front tarsus rather strongly enlarged (fig. 23); longer spur of the hind tibia slightly more than half the length of the basal segment of the hind tarsus; upper edge of the hind tibia, when this is seen from the side, with short, more or less outstanding hairs (45 degrees), most in evidence beyond basal third. Wings: 1st discoidal cell very distinctly stalked; transverse cubitus and recurrens interstitial or nearly so (fig. 9); upper surface of the median cell virtually bare, at most 2-3 hairs present distally. *Abdomen*: Petiole from 2 to $2\frac{1}{4}$ times as long as apically wide, only slightly widened towards apex and on the whole smoothly but a little brokenly striated throughout; seen from the side, its upper edge forms only a very feeble even curve (fig. 34); the sides of the petiole are not fused along the middle line ventrally (fig. 20).

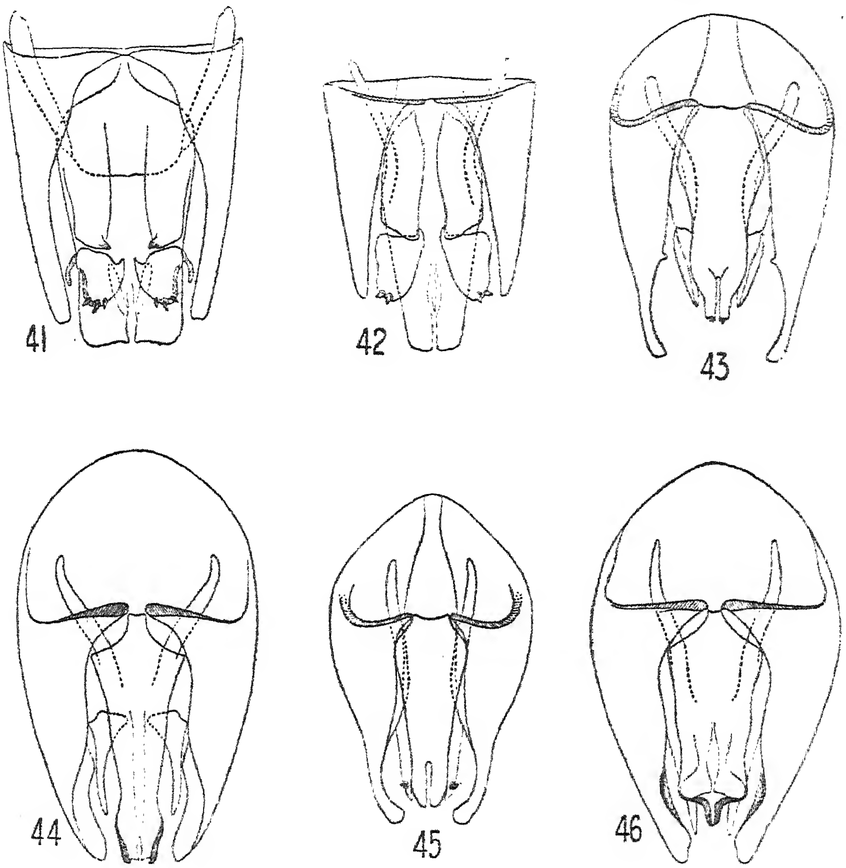
♂. Head more extensively pale marked than in the female, the entire face and usually the surface of the head behind the eyes, yellowish brown; in 2 out of 7 specimens, the pale mark at the temples is separated from the pale area around the base of the mandibles by a dark blotch. Pronotal collar and sides of the pronotum at least anteriorly, less often entirely, yellowish. Legs brighter in colour than in the female.

Length: ♂ ♀, 2-2·5 mm.

Uganda: Kawanda, January-March, 1943, 4 ♂♂, 3 ♀♀, ex nymphs of *Lygus* sp. D. on *Erigeron*; May-June, 1 ♂, 4 ♀♀, ex *Stenotus* sp. on grass; June, 1943, 1 ♀ (the type), ex nymph of *Megacoelum* sp. on sorghum; June, 1943, 1 ♂, 1 ♀, ex nymphs of *Lygus* sp. on sorghum; June, 1943, 1 ♂, ex nymph of *Corizidolon* sp. on *Cajanus*; October, 1942, 1 ♀, swept off cotton (*T. H. C. Taylor*). Serere, 2,

August, 1943, 1 ♀, ex nymph of *Stenotus* sp. on grass. Kampala, November, 1942, 1 ♀, ex *Lygus vosseleri*, Popp., on cotton (*G. L. R. Hancock*). All specimens bear the serial number " T.801 B ".

This species seems to belong to a group which is otherwise unrepresented in the material on which the present paper is based. The group appears to be characterised by the shape of the female antenna, the simple head with the non-convergent eyes, the stalked first discoidal cell and the unfused sides of the petiole.



FIGS. 41–46.—(41) *Euphorus meriones*, sp. n., ♂, genitalia (ventral); (42) *E. nigricarpus*, Szépligeti, ♂, same (ventral); (43) *E. carcinus*, sp. n., ♂, same (dorsal); (44) *E. prosper*, sp. n. ♂, same (dorsal); (45) *Euphoriella marica*, sp. n., ♂, same (dorsal); (46) *Euphorus choaspes*, sp., n., ♂, same (dorsal).

Euphoriella marica, sp. n.

♂ ♀. Dark brown. Legs also predominantly dark brown, the front pair being the palest, with their tibiae and tarsi obscure yellowish. Antennae yellowish on about basal half in the female but on about basal two-thirds in the male. Fore wing considerably clouded (fig. 6).

♀. *Head* from above subcubical. Eyes very large, very obliquely placed and strongly convergent on the face where the shortest distance between them is equal to half the longer diameter of one of them. Pubescence of the face inconspicuous and not at all dense, the hairs widely separated. Antenna 15-segmented,

hardly as long as head and thorax together; flagellum markedly thickened towards apex. Ocelli almost in an equilateral triangle. Frons and vertex finely rugulose-aciculate. *Thorax*: Mesonotum strongly shining, virtually bare, even around the anterior declivous part, without a trace of notaulices but with faint traces of obsolescent transverse aciculation. Propodeum very finely rugose-reticulate. Mesopleura strongly shining; below with traces of mostly scaly-reticulate sculpture but without a clearly defined impression. Inner spur of the hind tibia about one third as long as the basal segment of the hind tarsus; hairs of the upper surface of the hind tibia not in the least outstanding; apical segment of the front tarsus not markedly enlarged. Venation incomplete; radius just indicated at the wing margin; all other veins distal to the basalis more or less obliterated (fig. 6); submediellan cell of the hind wing not closed at apex; subcostella sclerotised throughout. *Abdomen*: Petiole very narrow, virtually parallel-sided; in profile very noticeably elbowed proximal to middle; the sides are fused beneath over fully basal two thirds.

♂. Antenna with 15 segments (4 exs.). Eyes not much smaller than in the female, the shortest distance between them about two thirds the longer diameter of one of them, 9:13. Genitalia (fig. 45).

Length: ♂ ♀, 1·6 mm. approx.

Uganda: Kawanda, October, 1942, 1 ♀, November, 1942, 2 ♀♀, 1 ♂, December, 1942, 1 ♀ (the *type*), all ex nymphs of *Sthenarus* on cotton; September-November, 1942, 3 ♂♂, 1 ♀, on cotton; June, 1943, 1 ♀ ex Capsid nymph (almost certainly *Sthenarus* sp.) on *Albizzia* (*T. H. C. Taylor*). All specimens bear the serial number " T.803 ".

I have examined a single female which at first sight appears to differ quite strikingly from *marica* but which on closer examination differs from that species in no particulars which could not, I think, be associated with a different and perhaps larger host. It was bred from a nymph of *Deraeocoris* on cotton (Kampala, March, 1930, *G. L. R. Hancock*). It is larger than females of *marica*, paler in colour, the head, thorax (except propodeal region) and tergite (2+3) being decidedly red-brown; the legs are paler, the front and middle pairs being virtually yellowish with only the apical tarsal segment darkened; the sculpture of the head and mesonotum is much more definite, the mesonotum showing pronounced transverse aciculation; as in *marica*, the antenna is 15-segmented, but the more distal segments are clearly longer than wide, whereas in *marica* they are virtually square in outline; the flagellum lacks, hence, the characteristic thickened appearance seen in *marica*.

According to Taylor, *Euphoriella marica* is a solitary, primary, internal parasite of *Sthenarus*. The period spent in the cocoon is 15-16 days.

The genus *Euphoriella* was erected by Ashmead in 1900 for an American species from Florida. At the time of writing his review of the Nearctic species of the subfamily EUPHORINAE in 1936, Muesebeck stated that the genus contained only the genotype species and one other that he himself was describing. He questions the validity of *Euphoriella* and expresses the opinion that it may eventually have to be combined with *Euphorus*. My use of Ashmead's genus, therefore, for an African species must be regarded as provisional and has no special significance.

Euphoriella is separated from *Euphorus* on wing venation which as Muesebeck rightly emphasises is very variable in *Euphorus*. It is probable that *Euphorus*, as constituted at present, could be split up into a number of genera but not on the basis of wing venation alone because this would lead to artificial groupings. When correlated with other characters, however, venational differences may be an index of diverging evolutionary lines within the genus. If my remarks are restricted to the species discussed in this paper, it seems that those species (*Euphorus lamius*, *E. prosper*, *E. choaspes*, *E. carcinus*, *E. ariomedes* and *Euphoriella marica*) in

which the recurrent vein is short, received into the 1st cubital cell or absent altogether, have the notaulices absent or almost so and the parameres of the male genitalia much longer on their ventral than on their dorsal side. Within this group of species, the wings may become somewhat narrowed and the venation much reduced (*Euphorus lamius* and *Euphoriella marica*).

Turning now to those species (*Euphorus meriones, E. anates, E. praetor* and *E. nigricarpus*) in which the recurrens is relatively long and either interstitial or received into the extreme base of the 2nd cubital cell, we find the wings broad, the venation showing no trace of reduction, the notaulices complete and the ventral and dorsal edges of the parameres virtually equal in length. It is possible that in these two major groupings of species within *Euphorus* may be found data to provide a good case for subdividing the genus. But before any such steps are taken, it is obvious that many more species of *Euphorus* must be examined to see whether the correlations of characters I have indicated are sound or not.

African Species of *Euphorus* not known to the Writer

1. *Euphorus xanthostigma*, Szépligeti, 1914, Rés. Sci. Voyage Alluaud, p. 197 (Kenya Colony).

2. *Euphorus krügeri*, Masi, 1933, Boll. Soc. ent. ital., **65** p. 131 (Tripoli).

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MERCURY AS A PREVENTIVE AGAINST STORED GRAIN PESTS.

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Introduction.

The losses caused to stored grain in India by insect pests has recently been estimated by Rahman (1942) to be at least 25 million maunds annually. This loss is particularly serious in the case of grain stored by peasants in mud bins and in gunny bags by householders, merchants, and others. Carbon bisulphide and other fumigants which have been employed so successfully in other countries against these pests cannot be used in India because of the illiteracy and poverty of the cultivators and the absence of air-tight storage facilities. Free mercury and tin amalgam can, however, be used with safety, and it was, therefore, decided to test the efficiency of these substances. The results are presented in this paper.

Historical.

Kunhi Kannan (1920) observed Mysore zamindars using mercury in small vessels to check the increase of the pulse beetle, and was the first to draw the attention of entomologists to the use of mercury against pests of stored grains. Ayyar (1921) also observed South Indian cultivators using mercury in the same way as their Mysore compatriots. Larson (1922) studied the effect of it on the eggs and larvae of *Bruchus quadrimaculatus*, F., and found that the eggs were killed whilst the larvae were affected adversely. Dutt and Puri (1929) recommended the use of tin amalgam in small containers of a few seers capacity to protect the grain from attack. Gough (1938) found that mercury vapours were toxic to the eggs of *Tribolium confusum* but other stages were not adversely affected. Wright (1944) investigated the effect of mercury and compounds of mercury in the laboratory and concluded that mercury vapours were fairly effective in preventing reproduction of *Calandra granaria*, L., *Oryzaephilus surinamensis*, L., *Rhizopertha dominica*, F., and *Sitotroga cerealella*, Ol. Zinc and tin amalgam and calomel were found to be less effective.

Systematic tests with mercury have so far been confined to the laboratory, and its effect on insect pests in large containers has not been investigated. Our experiments have been designed to examine thoroughly the possibilities of mercury as a preventive against stored grain pests in large receptacles, the minimum effective dose and a suitable method of application.

Laboratory Trials with Metallic Mercury and Tin Amalgam against *Trogoderma granarium*, Everts.

Experiment 1.

Small earthern vessels and empty kerosene oil tins (one gallon capacity), each containing four seers of sound wheat were used. The mercury, in small cloth bags (3 in. × 3 in.) at the rate of 2·5 tolas (3 = 1 oz.) per maund (= 40 seers = 82 lbs.) of wheat, was placed at the bottom and just below the top layer of grain. Tin amalgam was prepared according to the method recommended by Dutt and Puri (1929) and used at the rate of 4·25 tolas per maund of wheat. It was beaten into a small disc of 2·1 in. diameter which, after being wrapped in a filter paper, was

placed just below the top layer of grain. One hundred grubs of *Trogoderma granarium*, Everts, were introduced into each container, the mouths of which were closed with mud plaster. There were four replications of each treatment in each type of container. The experiment was set up in June and concluded in July of the next year. The results are given in Table I.

TABLE I.

Average Population of *Trogoderma granarium* under different Treatments.

Treatment	Population of *T. granarium*							
	Earthen vessel				Kerosene oil tin			
	No. of living larvae	No. of dead larvae	No. of dead adults	Total	No of living larvae	No. of dead larvae	No. of dead adults	Total
Control	1104	653	521	2278	889	528	590	2007
Tin amalgam ...	539	378	405	1322	662	688	543	1893
Free mercury ...	22	3	92	117	16	10	103	129

The above results show that metallic mercury almost checked the reproduction of *T. granarium*, whereas it continued in a normal manner in the presence of tin amalgam.

Experiment 2.

The experiment with tin amalgam was repeated, increasing the amount to 13·52 tolas per maund of wheat. The technique adopted was the same as for the previous experiments. Three hundred grubs of *Trogoderma granarium* were introduced into each container. The experiment was started in July and concluded in the following April. The results are given in Table II below:—

TABLE II.

Average Population of *Trogoderma granarium* under different Treatments.

Treatment	Population of *T. granarium*					
	Earthen vessel			Kerosene oil tin		
	No. of living larvae	No. of dead adults	Total	No. of living larvae	No. of dead adults	Total
Control	3225	515	3740	2904	520	3424
Tin amalgam	3694	541	4235	2730	461	3191

The above results show that tin amalgam, even with as high a dose as 13·5 tolas per maund of wheat, did not prove effective against *Trogoderma granarium*.

Large Scale Trials with Metallic Mercury and Tin Amalgam in Mud Bins.

Method and Material.

Experiments were conducted in mud bins (fig. 1) of 9½-25 maunds capacity at four different places in the Punjab, *viz.*, Risalewala, Jullundur, Gurdaspur and Lyallpur, during June-August, which is the active season for the stored grain pests. Sixty-four to sixty-seven maunds of wheat were stored under each treatment at the four places, but at each station the amount of wheat under one treatment varied from 9½-25 maunds, depending upon the size of the bin. About 2½ maunds of wheat heavily infested with *Trogoderma granarium*, Everts, *Calandra oryzae*, L., and *Tribolium castaneum*, Hbst., were added to each bin to initiate the infestation, the rest of the wheat being perfectly sound and insect-free. The infested wheat was attacked to the extent of 13 per cent., 14·5 per cent., 12·2 per cent. and 13·9 per cent. and constituted 21·8 per cent., 24·7 per cent., 10 per cent. and 12·2 per cent. of the total wheat in each bin at Risalewala, Jullundur, Gurdaspur and Lyallpur respectively.

FIG. 1.—Mud bins.

Mercury was used at the rate of 2½ tolas, 3½ tolas, 4½ tolas and 4 tolas per maund of wheat at Risalewala, Jullundur, Gurdaspur and Lyallpur respectively. It was applied in cloth bags 3 ins. square, each bag containing about 1 tola of mercury. As *Trogoderma granarium* is most serious in the upper 10-12 in. layer of the grain, the bags containing mercury were so distributed in the bin that 44-47 per cent. were in the upper layer while the remainder were distributed throughout the rest of the bin with an 8-12 in. thick column of wheat between the two successive layers (Table III). In one bin at Lyallpur, mercury was used at the bottom and upper 10-12 in. layer while the intervening column of wheat was left untreated.

Tin amalgam was prepared as before and used at the rate of 3¾, 5, 6 and 9 tolas per maund of wheat at Risalewala, Jullundur, Gurdaspur and Lyallpur respectively. For application, it was beaten into discs, each weighing one tola and measuring 2½-3 in. diameter, which after wrapping in filter papers were distributed in the bin in the same manner as the mercury.

There was only one replication of each treatment at each station; the treated wheat was examined 9-13 months after the treatment.

TABLE III.

Distribution of Mercury in the Bins at different Depths at different Places.

Risalewala		Jullundur		Gurdaspur		Lyallpur	
Distance from the bottom	Quantity of mercury	Distance from the bottom	Quantity of mercury	Distance from the bottom	Quantity of mercury	Distance from the bottom	Quantity of mercury
0-ins.	6 tolas	0-ins.	5 tolas	0-ins.	13 tolas	0-ins.	9 tolas
12-ins.	$4\frac{1}{2}$ tolas	12-ins.	4 tolas	10-ins.	13 tolas	8-ins.	9 tolas
30-ins.	6 tolas	24-ins.	4 tolas	20-ins.	12 tolas	16-ins.	9 tolas
52-ins.	$13\frac{1}{2}$ tolas	36-ins.	5 tolas	30-ins.	12 tolas	25-ins.	9 tolas
		48-ins.	5 tolas	40-ins.	12 tolas	34-ins.	8 tolas
		54-ins.	6 tolas	50-ins.	13 tolas	44-ins.	7 tolas
		58-ins.	5 tolas	54-ins.	18 tolas	49-ins.	14 tolas
				58-ins.	19 tolas	53-ins.	15 tolas

Height × diameter of bin at Risalewala $4\frac{1}{2}$ ft. × $2\frac{1}{2}$ ft., at Jullundur 5 ft. × top $1\frac{1}{2}$ ft. and bottom 2 ft., at Gurdaspur $5\frac{5}{8}$ ft. × $3\frac{1}{3}$ ft., and at Lyallpur $5\frac{3}{4}$ ft. × 3 ft.

The relative efficiency of mercury and tin amalgam was determined in the following manner.

(a) *Presence or absence of insects in treated and untreated bins.*

The insects multiplied freely in the control as well as in amalgam-treated bins at all the stations; consequently a large number of larvae of *Trogoderma granarium* and of the adults of *Tribolium castaneum* were seen on the lids and naked sides of the bin*. This was further supported by the fact that the top of the grain under both these treatments was found to be covered with a thick layer of *T. granarium* moults, underneath which the active insects were found in large numbers. The mercury treated bins at Jullundur, Gurdaspur and Lyallpur, on the other hand, were found to be absolutely free from all the stored grain pests, and no living insect was met with either on the lid, sides of the bins or among the grain. At Risalewala and Lyallpur (where mercury was used at the bottom and top layer only), there was some evidence of insect activity but it was at a much reduced rate as compared with the control.

In support of these observations comparative populations under each treatment were also worked out at Lyallpur, and for this purpose 161 grammes of wheat were taken from the top of each bin and the insects therein counted very carefully. The results are presented in Table IV below:—

TABLE IV.

Population of *T. granarium* and *T. castaneum* in a Sample of Wheat weighing 161 grammes.

Treatments	*Trogoderma granarium*				*Tribolium castaneum*			
	Larvae	Pupae	Adults		Larvae	Pupae	Adults	
			Dead	Living			Dead	Living
Control	3716	—	2452	776	4	—	—	10
Mercury throughout ...	—	—	550	—	—	—	—	—
Mercury at top and bottom	22	39	1298	19	—	—	50	1
Tin amalgam	2200	—	3485	650	2	—	1	—

It will be observed from the above table that the sample of wheat from the bin in which mercury was distributed throughout was free from living insects.

* In the control bin at Lyallpur, 11,373 grubs of *T. granarium* and 247 adults of *T. castaneum* were counted on the lids and naked sides of the bin, whereas in tin amalgam treated bin, the corresponding figures were 6,593 and 244 respectively.

(*b*) *Percentage of attack.*

In order to calculate the percentage of attack in the entire lot of wheat in a bin, its contents were taken out and thoroughly mixed. Twenty small random samples were then taken from all over the heap and these again thoroughly mixed. From this, 3,000-4,000 grains were taken and the attacked and sound grains in the sample counted. Results are presented in Table V below:—

TABLE V.

Percentage of Attack.

Treatments	Percentage of attack					
	Risalewala			Jullundur		
	No. of grains examined	Attacked grains	Percentage of attack	No. of grains examined	Attacked grains	Percentage of attack
Control	3288	284	8·6	3546	1307	36·9
Tin amalgam	4424	326	7·4	3312	2191	41·9
Mercury throughout ...	3590	132	3·7	3623	52	6·9
Mercury top and bottom	...	...	...	...	...	...

Treatments	Percentage of attack					
	Gurdaspur			Lyallpur		
	No. of grains examined	Attacked grains	Percentage of attack	No. of grains examined	Attacked grains	Percentage of attack
Control	3395	1042	33·7	3411	722	20·9
Tin amalgam	3541	617	17·4	3896	738	18·9
Mercury throughout ...	3370	72	2·1	3012	184	6·1
Mercury top and bottom	...	...	...	4766	398	8·3

(*c*) *Percentage loss in weight.*

Loss in weight due to insect attack was worked out at Jullundur and Lyallpur only. For this purpose, wheat from each bin was taken out, thoroughly sieved, winnowed to remove frass (fig. 2) and then weighed. Results are given in Table VI below:—

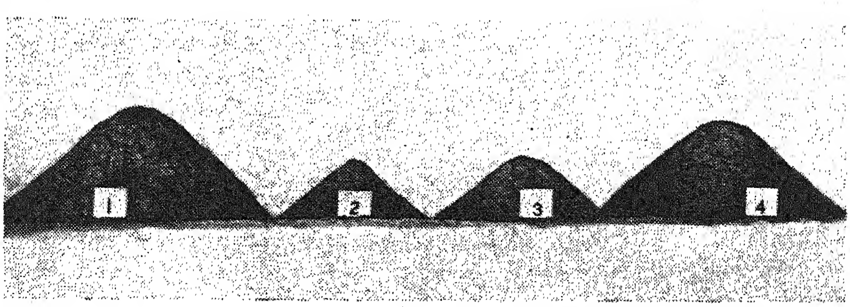

FIG. 2.—Showing amount of frass produced by *T. granarium* in mud bins at Lyallpur. (1) control; (2) treated with mercury throughout; (3) mercury top and bottom; (4) tin amalgam.

TABLE VI.

Percentage of Loss in Weight due to Insect Attack.

Locality	Treatments	Amount of wheat stored	Amount of wheat recovered	Actual loss	Percentage of loss in weight
		mds. srs.	mds. srs.	mds. srs.	
Jullundur ...	Control	9 14	8 14	1 0	10·69
	Tin amalgam ...	9 39	8 17	1 22	15·53
	Mercury	9 31	9 29	0 2	0·51
Lyallpur ...	Control	20 18	18 20	1 38	9·5
	Tin amalgam ...	20 20	18 23	1 37	9·3
	Mercury throughout	20 19	20 17	0 2	0·24
	Mercury at top and bottom.	18 23	18 8	0 15	2·1

It will be observed from the above table that in the bins treated with mercury, the loss was negligible whereas with tin amalgam the loss was more than in the control at Jullundur and as high as the control at Lyallpur.

The above results (Tables IV-VI) show that mercury distributed throughout the bin at the rate of $3\frac{1}{2}$-4 tolas per maund of wheat proved effective in completely checking the increase of the insect pests thereby saving the grain from damage. Mercury used at the bottom and in the top 10-12 in. layer of grain only, proved fairly effective and the loss of wheat was far less than under the control. Tin amalgam in all the doses, however, proved quite ineffective and the insects continued to multiply normally. It may also be mentioned that even under a higher dose (*i.e.*, $13\frac{1}{2}$ tolas per maund of wheat) of tin amalgam *T. granarium* multiplied 14·1 times in ten months as against 12·5 times in the control.

Dutt and Puri (1929) on the basis of their experiments recommended the use of tin amalgam to check stored grain pests. It is evident, however, from the technique they followed that they used insect-free wheat in insect-proof containers, and under these circumstances there might have been no attack even without the use of tin amalgam. In the absence of any control, their experiments and conclusions cannot be relied upon. Our observations with tin amalgam in varying doses in earthern containers of variable size do not support their conclusions. Isaac (1930) also reported large numbers of adults of *Tribolium castaneum* on the top layer and a large number of *Silvanus surinamensis* in the bottom layer of rice treated with tin amalgam in a bin at Ranchi. The results obtained by Wright (1944) with tin amalgam against grain weevil were also not very conclusive since he reported that " substantial increase occurred in the presence of tin amalgam which, when first used (experiment 2) appeared fully effective ".

(*d*) *Cost.*

On exposure, free mercury gives off emanations under natural conditions, but it was found that the amount so lost was negligible. At Lyallpur 78 tolas out of 80 tolas were recovered after $10\frac{1}{2}$ months, while at Jullundur there was a loss of only one of 34 tolas in $13\frac{1}{2}$ months. Consequently, mercury once purchased can be used year after year provided that the bags are carefully handled and stored when not in use. The annual recurring cost of mercury, therefore, would be far less than the benefit derived from the elimination of insect attack. Taking the cost of mercury at 1·2 annas (one rupee=16 annas=1*s.* 4*d.*) per tola (pre-war rate), an expenditure of 1·2 annas at Jullundur and 2·4 annas at Lyallpur saved one maund (Rs. 2/10/-) and one maund 38 seers (Rs. 3/10/6) of wheat at the above stations respectively.

It may also be added that mercury treated wheat fetched a premium of 0·25 annas to 1·5 annas per maund (Table VII) in the grain market over the untreated grain.

TABLE VII.

Premium fetched by mercury-treated Wheat in the Market over the untreated grain (pre-war figures).

Treatment	Jullundur		Lyallpur	
	Rate per maund	Premium over the control	Rate per maund	Premium over the control
	Rs. As. Ps.	Annas	Rs. As. Ps.	Annas
Control	2 8 6	...	1 12 9	...
Tin amalgam	2 8 0	—0·5	1 12 9	...
Mercury throughout	2 10 6	+1·5	1 13 6	+0·75
Mercury top and bottom ...	...	...	1 13 3	+0·5

The above data show that there are two advantages in the inclusion of mercury with stored wheat: firstly elimination of loss due to insect attack and secondly the higher price realised. It is estimated that there was a net gain of Rs. 3/6/9 and Rs. 4/5/7 by treating 10 maunds and 20 maunds of wheat with mercury at Jullundur and Lyallpur respectively, which shows that storing of wheat in bins with mercury is both effective and economical.

Large Scale Trial with Mercury in Metallic and Bamboo Bins.

The farmer may make bins of earth, metal or bamboo (Rahman, 1942). Mercury was tested in these bins and the results are presented below:—

Metallic bins.—(i) Ten maunds of wheat heavily infested with *T. granarium* were treated with mercury in a metallic bin in July, 1940, at the rate of 4 tolas per maund of wheat, and an equal quantity of wheat in another bin was kept as control at Shahbazpur (District Hoshiarpur). The experiment was concluded in August, 1941. When readings were taken, it was found that in the treated bin the multiplication of *T. granarium* and *Rhizopertha dominica* had been completely checked and the percentage of attack and percentage of loss in weight was 6·3 and 0·5 as against 13·6 and 5·5 in the control bin respectively.

(ii) Similarly 20 maunds of wheat infested with *T. granarium* to the extent of 11·8 per cent. was treated with mercury in May. Mercury was used at the rate of 3½ tolas per maund of wheat and distributed throughout the bin. The metallic bin was examined in June of the following year, when it was found that the pest had been completely checked and no living insects were found. The percentage of infestation was worked out at 12·6.

Bamboo bin.—Eight maunds of wheat in a bamboo bin (fig. 4) were treated with mercury at the rate of 4 tolas per maund of wheat at Palampur (District Kangra). The bamboo bin, in accordance with the practice of cultivators, was given three coatings of a mixture of dung and mud to seal any chinks, but because of cracking on drying it could not be made air-tight and the insects from one bin could infest the grain in the other. This experiment was started in July, 1939, and concluded in the same month in 1940. It was observed that the insects* in

* In the infested wheat used for introducing infection in the bin, *Calandra oryzae*, L., *Rhizopertha dominica*, F., *Tribolium castaneum*, Hbst., *Silvanus surinamensis*, L., *Sitotroga cerealella*, Ol., and Cadelle beetle were present.

the mercury treated bins had increased very slightly compared with those in the control. In a sample of grain weighing 18 ozs. taken from each bin, the population of adult insects was 224 in the mercury treated grain as against 672 in the untreated, giving an attack of 20·3 per cent. in the former and 61·9 per cent. in the latter. Loss in weight as a result of insect attack was also much higher in the control bin, being 30·9 per cent. as against 10 per cent. under mercury.

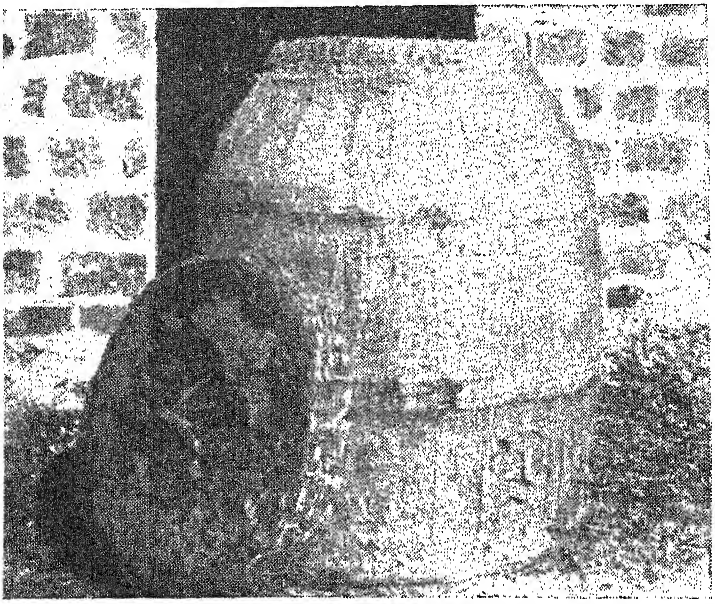

FIG. 3.—Bamboo bin.

Effect of Mercury on the Germination of Wheat.

The effect of mercury on the germination of wheat was studied in small air-tight glass jars in the laboratory. Wheat 8A was selected for this purpose. Germination tests were carried out on moist filter papers in petri dishes. The results are tabulated below:—

TABLE VIII.

Effect of Mercury on Germination of Wheat.

Duration of the experiment	Percentage of germination	
	Treated wheat	Un-treated wheat
30th Nov. to 22nd May	86·75	81·25
30th Nov. to 12th Sept.	85·0	83·0

It will be observed from the above table that mercury, if anything, rather stimulated the germination of wheat, as already observed by Dutt and Puri (1929).

Effect of Mercury on different Stages of *T. granarium*.

Two earthen cylindrical jars with tightly fitting lids were used to study the effect of mercury on different stages of *T. granarium*. In one of these mercury was put and an equal number of the different stages of " khapra " was placed in small dishes in both jars and their development studied.

Egg Stage.

In the jar with mercury, no embryos developed and the eggs gradually shrivelled up. In the jar without mercury, however, all the eggs hatched successfully in 3-4 days. Similar results were also obtained with the eggs of *Bruchus* sp. These results confirm the findings of Larson (1922), Kunhi Kannan (1924), Dutt and Puri (1929), Gough (1938) and Wright (1944).

The minimum exposure required to bring about a 100 per cent. mortality of eggs was also determined by keeping the fresh eggs for 15, 35, 55 and 60 minutes in the jar containing mercury. It was found that a minimum exposure of one hour was essential to kill them completely. Because of the convenience in handling, only eggs of *Bruchus* sp. were used for these experiments.

The effect of mercury on the developing embryo was also studied by placing *Bruchus* eggs in different stages of development (*i.e.*, 0, 24, 48, 72, 96 hours after they were laid) in an earthen jar containing mercury. For this purpose, 150 fresh eggs were obtained on 23rd July between 8-12 a.m. and batches of 20 eggs each with different embryonic development, *i.e.*, 0 per cent., 20 per cent., 40 per cent., 60 per cent., and 80 per cent. were taken from this lot and placed in the jar with mercury on 23rd July, 24th July, 25th July, 26th July, 27th July, respectively. It was observed that the eggs in which the embryo had completed up to 60 per cent. of its development were effectively killed by mercury but beyond that stage of development the embryo remained quite unaffected and hatched normally (Table IX). It may be mentioned that the control eggs hatched in 120 hours.

TABLE IX.

Effect of Mercury on the developing Embryo.

Age of eggs	Freshly laid	24 hours	48 hours	72 hours	96 hours
Percentage of embryonic development	0	20	40	60	80
28th July	No development	No development	No development	Slight development in three	All hatched
29th ,,	do.	do.	do.	None hatched	All entered the grain
30th ,,	do.	do.	do.	All dead	—

Larval stage.

The rate of growth of larvae placed in the jar containing mercury was appreciably retarded but those placed in the jar without mercury grew normally; for example " khapra " larvae completed their larval stage in 24-40 days in the former and 16-34 days in the latter case (Table X).

TABLE X.

Duration of Larval Stage of *T. granarium* under Mercury and Control.

Control			Mercury		
Date of pupation	No. of larvae pupating	Duration of larval stage (in days)	Date of pupation	No. of larvae pupating	Duration of larval stage (in days)
23rd July	1	16	31st July	2	24
25th ,,	1	18	1st Aug.	1	25
28th ,,	2	21	3rd ,,	1	27
31st ,,	2	24	5th ,,	1	29
1st Aug.	3	25	6th ,,	1	30
3rd ,,	3	27	10th ,,	1	34
4th ,,	2	28	13th ,,	1	37
10th ,,	2	34	15th ,,	1	39
—	—	—	16th ,,	1	40

(Number of observations = 18) (Date of hatching = 7th July)

In another set of experiments, 23 freshly hatched larvae of *T. granarium* were placed in a jar containing mercury and the same number was kept in the control jar. It was observed that 22 of the larvae successfully completed their larval stage in the mercury jar as against 18 in the control. Similarly 37 larvae of *Bruchus* sp. out of 40 under observation, successfully emerged as adults under mercury in 22-29 days and the same number under control in 18-22 days. This shows that beyond retardation in the rate of growth, mercury has no adverse effect on the larvae. The results obtained by Larson (1922) with *Bruchus quadrimaculatus* may either have been purely accidental or the higher mortality obtained under mercury may have been due to some other causes such as fungus, etc., which he observed interfering with his experiment.

Pupal stage.

Mercury did not affect the pupal stage in any way. Pupae kept in the jars with mercury and without mercury gave rise to adults in 4-6 days.

Adult stage.—Adults were slightly affected by mercury; for example the adults which emerged from the above-mentioned pupae laid 12-45 eggs, with an average of 27·4 eggs in the jars with mercury and 27-34 eggs with an average of 31·5 in the jars without mercury.

Summary.

Mercury and tin amalgam were tried in mud bins, metallic bins and bamboo bins at different places in the Punjab. Mercury distributed throughout the bin at the rate of 3-4 tolas per maund of wheat proved effective in completely checking the increase of various stored grain pests. Mercury used at the bottom and top 10-12 in. layer of grains in the bin also proved fairly effective. Tin amalgam even with as high a dose as 13½ tolas per maund of wheat did not prove effective. Loss of mercury during use is very slight. Mercury has no deleterious effect on the germination or eating quality of wheat.

Mercury kills the fresh eggs of stored grain pests, but the eggs in an advanced stage of development are not adversely affected. It retards the growth but does not kill the larvae of *T. granarium* and *Bruchus* sp. It has no effect on the pupae, but affects the egg laying capacity of adults very slightly.

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Cost of the adhesive.

At Ibadan, the present price of coagulated latex is 1s. 0d. per lb. and of shea butter 6d. per lb.; at these prices the cost of the adhesive (4 parts latex to 1 part shea butter by weight) required to treat 100 wires is about 5d.

"Atẽ" Adhesive against Houseflies.

Method of trapping.

Ten wires are suspended from a horizontal string over the kitchen table on which food is prepared. It is advisable to attach a square piece of wood (about 2 in. × 2 in.) to the lower end of each wire as, very occasionally, when the kitchen is very hot a mass of struggling flies and adhesive is liable to drop off the wire. The end of the wire can be inserted in a hole in the centre of the wood. It has been found that trapping in the kitchen reduces the fly infestation in the living quarters of a house to negligible proportions; it has never been necessary to suspend wires in the house itself.

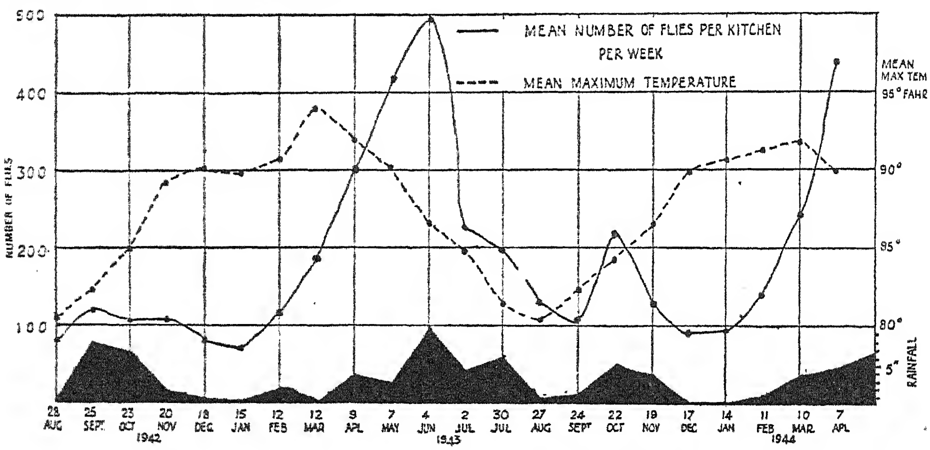

FIG. 1.

Trapping results.

From 31st July, 1942, to date, trapping has been carried out in the kitchens of all occupied houses on Moor Plantation, Ibadan, the headquarters of the Nigerian Agricultural Department. From the inception of trapping to 21st April, 1944, six broom strands were placed in each kitchen once a week; during the period of maximum infestation catches of over 700 flies were made in certain kitchens during one week. As the capacity of a broom strand is only about 130 flies it was evident that, when flies were very abundant, a total capacity of about 780 was inadequate. From 22nd April, 1944, to date, 10 wires, with a total capacity of about 2,000 flies, have been used in each kitchen. The catches were counted each week from 7th August, 1942, to 28th July, 1944, and, subsequently, fly incidence has been estimated once a month. The experimental counts proved to have a practical value as, on several occasions, when two or three neighbouring houses were found to be particularly heavily infested it was possible to discover the breeding source and to eliminate it. For this reason the counts have been continued after the conclusion of the experimental counts on 28th July, 1944.

The number of flies trapped in each kitchen was determined weekly. Fly incidence, for the period when six strands were used per kitchen, is depicted graphically in figure 1; the mean number of flies trapped per kitchen is shown for 22 four-weekly periods. The total number of flies caught in the four-weekly

period was divided by the number of times on which trapping was carried out. Maximum infestation occurred in the week ending on 14th May, 1943; the upward trend first became evident in mid-February of both 1943 and 1944. This increase appears to be correlated with the rise in temperature at that time and is probably the result of a reduction in the duration of larval development. Derbeneva-Ukhova (1) has shown that, at a relative humidity of 70-80 per cent., the larval stages of *Musca domestica*, L. (in pig dung), were shortest at a temperature of 93·2°F.; at that temperature the stages averaged only 3·1 days with a minimum of 2·5 days. The mean relative humidity at 14.00 hours at Ibadan was only 48 per cent. in February, 1943, and 43 per cent. in February, 1944; each was the lowest monthly mean of the year. There did not appear to be a correlation between fly incidence and relative humidity. Exceptionally heavy showers of rain fell on 25th January, 1943, and on 16th January, 1944 (1·57 in. and 1·22 in. respectively); but, in 1945, the upward trend also occurred in February after a rainless January (February, 1945, was also rainless). A downward trend in fly incidence became evident in the second half of July, 1943, when the mean maximum temperature was decreasing rapidly; the temperature fell from 84°F. in the week ending 30th June to 79°F. in the week ending 28th July. The mean relative humidity at 14.00 hours was 73 per cent. in June and 79 per cent. in July. The low adult incidence in the four weeks ending 24th September, 1943, followed a period of both low temperature and low rainfall; only 1·45 ins. of rain fell between 25th July and 12th September.

The total number of flies trapped during the two years was 272,498, and the mean catch per kitchen per week was 269. The vast majority of the flies were *Musca domestica vicina*, Macq., occasionally *M. cuthbertsoni*, Patt., was present.

The houses on Moor Plantation are in two groups, ten are situated in an area of about 18 acres to the south of the Lagos-Ibadan road and seven others in an area of about 26 acres to the north of that road. The minimum distance between the two groups is about 550 yards. In the two years of trapping the mean number of flies taken in the northern group exceeded the southern group mean in 87 out of 104 weeks; the mean catch per kitchen per week over the whole period was 324 for the northern group and 234 for the southern group. In both groups the houses on the southern fringe were the most heavily infested. The probable explanation of this is that the prevailing winds during the time when flies are abundant come from the south, south-south-west and south-west. A large military camp lay to the south-west of the southern group; whilst there were many quarters occupied by Africans to the south-south-east of the northern group.

Time of trapping Experiment.

Six strands were placed in a kitchen at 09.00 hours on 30th April, 1943, counts were made at hourly intervals until 19.00 hours and from 07.00 to 09.00 hours on 1st May. The results are shown in Table I below.

TABLE I.

Period of trapping	Number of flies caught	Period of trapping	Number of flies caught
30th April		30th April	
9 to 10 hrs.	10	16 to 17 hrs.	8
10 to 11 hrs.	11	17 to 18 hrs.	8
11 to 12 hrs.	4	18 to 19 hrs.	23
12 to 13 hrs.	11	19 hrs. to 7 hrs. on 1st May (12 hrs.)	7
13 to 14 hrs.	14	7 to 8 hrs.	2
14 to 15 hrs.	14	8 to 9 hrs.	10
15 to 16 hrs.	4		

The largest hourly catches were made during the preparation of luncheon and dinner; but the relatively large catch between 18.00 and 19.00 hours took place when dusk was falling.

Trapping data.

In kitchens the greatest number of flies is trapped on the wires in the middle of the row and the number caught per wire decreases towards each end of the row. This is due to the fact that flies entering a kitchen settle on the table, usually near its middle, and then fly upwards to the wires.

On 17th March, 1944, four wires (diameter 4 mm.) and four strands (midribs of oil palm leaflets) were suspended alternately over a kitchen table. Of 598 flies trapped in the first 24 hours, 41 per cent. were on the strands and 59 per cent. on the wires; during the next two days a further 623 flies were caught, of these 41 per cent. were on the strands and 59 per cent. on the wires. Unlike *Ephestia*, flies make vigorous efforts to escape when they come in contact with the adhesive and, if they happen to be attached by only one or two legs in the first place, they sometimes succeed in freeing themselves. The diameter of the strands is only 1·5 mm., and it seems probable that the greater surface of adhesive on the wires results in there being fewer escapes. It is possible that the metal of the wires, being a better conductor of heat, improved the viscosity of the adhesive. Similar experiments were carried out in the pig pens, where both *Musca* and *Stomoxys* were present. The results are shown in Table II. Ten wires and ten strands were used on each day.

TABLE II.

Date	Total no. of flies caught in 24 hours.	Percentage *Stomoxys*	Percentage on wires	Percentage on strands
1943				
2nd Nov.	785	24	83	17
9th „	661	21	73·5	26·5
16th „	654	15·5	68	32
23rd „	587	3	64·5	35·5
30th „	1052	2	56	44

Oil palm strands were used on 2nd Nov. and wine palm (*Raphia*) strands on the other dates. It will be seen that the relative efficiency of the strands increased as the *Stomoxys* population decreased. From observation, *S. nigra* appeared to be more successful than *Musca* in its efforts to free itself when lightly attached to the adhesive.

The number of flies trapped during the first 24 hours always exceeded the number caught on any subsequent day; the total taken on days 2 to 7 was only 2 to 3 times as great as the number caught during the first day. Eight experiments were carried out in which newly-made " até " was tested against 3 day old " até ". An observer counted the number of flies attracted to old and new " até " wires and also the number of flies escaping from each type; in each experiment the observations were made during the first hour after the wires were suspended. Of the total number of flies alighting on the wires, 54·5 per cent. were on new " até " and 45·5 per cent. on old; five times as many flies succeeded in escaping from the old " até " as from the new. It seems that viscosity decreases rapidly and that, in fly-trapping, the wires should be renewed at frequent intervals, say every third or fourth day. The new wires were more attractive to flies than the old, probably on account of the odour of freshly prepared " até ", which somewhat resembles that of ripe Stilton cheese.

The Gold Coast Department of Agriculture prepares an adhesive, known as "Ephesticide", which is sold in tins to local firms for use against *Ephestia cautella* in cocoa stores. The writer has been informed by Mr. H. E. Box that the formula is based on that of the "até" adhesive. On 26th January and 16th March, 1945, five wires coated with "Ephesticide" and five with (4:1) "até" were suspended alternately in a kitchen. In each test counts were made after 24 hours and again after a further six days. The results are shown in Table III.

TABLE III.

Period	Number of flies on "até"	Per cent.	Number of flies on "Ephesticide"	Per cent.
1945				
26–27 Jan. ...	39	65	21	35
26 Jan.–2 Feb. ...	178	61	112	39
16–17 Mar. ...	81	72	32	28
16–23 Mar. ...	517	79·5	133	20·5

The mean maximum shade temperature was 93·7°F. during the first trapping period and 94·8°F. during the second. It will be seen that, during the two weeks, nearly three times as many flies were trapped by "até" as by "Ephesticide". An opportunity has not yet been found for comparing the effectiveness of the two adhesives against *Ephestia cautella* in cocoa stores. In the writer's opinion, "Ephesticide" is of too thin a consistency to be an effective adhesive for use in stores with a high temperature, especially those with corrugated iron roofs.

"Atē" Adhesive against *Stomoxys* spp.

Early in June, 1942, biting flies were reported to be numerous in some new pig pens on Moor Plantation. Flies were collected from the pens and of 131 biting flies taken, 122 were *Stomoxys nigra*, Macq., and 9 were *S. calcitrans*, L.

There are 12 pens arranged in two rows, one facing due north and the other due south. Each pen is 20 ft. long and 6 ft. 8 ins. wide and is divided by a low wall (3 ft. 4 ins. high) and a door into two sections, an inner pen with a thatched roof and an open yard. It was found that many *Stomoxys* were present in the inner pens during the daytime and screens made of oil palm fronds were erected over the low wall and door; after this was done *Stomoxys* was troublesome only in the outer yards. Strands suspended in both the inner pens and outer yards showed that the best trapping site was under the eaves of the thatched roof. Horizontal strings were therefore tied under the eaves of each row of pens; ten strands (at 8 in. intervals) were attached to the string in front of each pen. The strands were put up every Tuesday and the fly counts were made 24 hours later; occasional counts made after one week indicated that the catch for days 2 to 7 was only from one to two times as great as that on the first day.

Trapping results.

Strands were used from 27th October, 1942, to 11th April, 1944, and wires from 18th April to 13th December, 1944. The total capacity of 120 strands is about 15,600 flies and, as the maximum catch in 24 hours was only 6,714 flies, the experimental counts on strands and wires are comparable. From the control point of view the capacity of the strands was probably inadequate at times of maximum infestation.

Figure 2 shows the trapping results for the 112 weeks; the 24-hour counts are grouped in fours. The total shown for each four week period represents the sum of four counts and not the total number of flies trapped during the 28 days. From 23rd December, 1942, onwards the approximate number of *Stomoxys* and non-biting flies was estimated by visual examination. The only method of obtaining accurate figures is to remove the flies and "até" by soaking the wires in kerosene; this laborious process was carried out over a period of 21 weeks, and it was found that the number of *Stomoxys* estimated visually was only about 2 per cent. less than the actual number present.

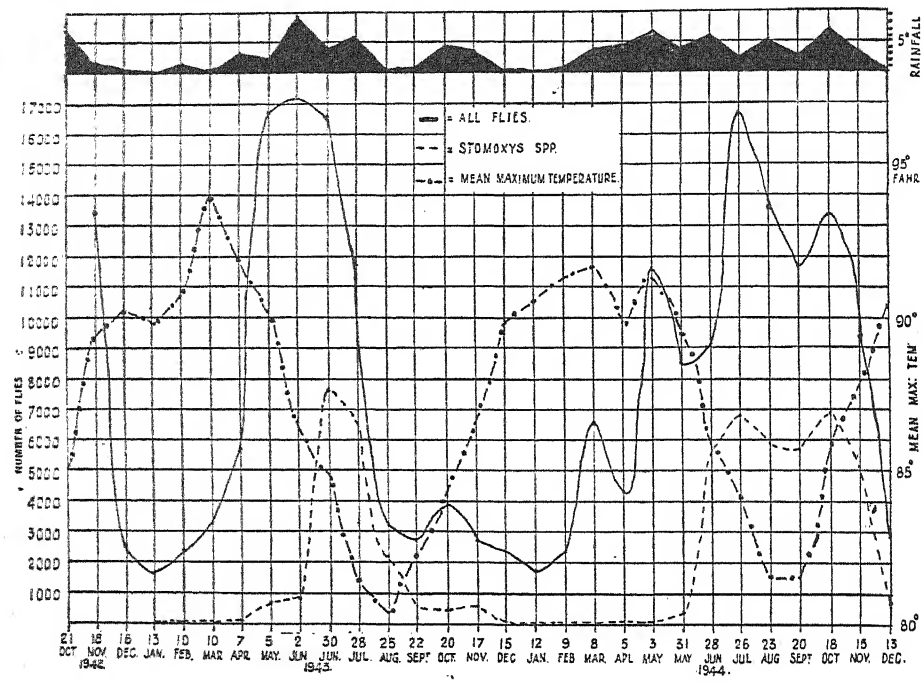

FIG. 2.

It will be seen that the non-biting fly (about 90 per cent. *Musca domestica vicina*) curves agree closely with those in figure 1; in 1943 maximum infestation also occurred in the second week of May. *Stomoxys* incidence is closely correlated with rainfall. As stated above, only 1·45 ins. of rain fell between 25th July and 12th September, 1943, and *Stomoxys* was comparatively rare after mid-August; in 1944, the rainfall was well distributed, and there was no "short dry season". *Stomoxys* was abundant up to the end of November. In each year (including 1942) *Stomoxys* incidence increased rapidly during June. Very few *S. nigra* are present during the dry season (December to February), and, after the onset of the rains in March, several generations are required to build up the population; the life cycle (from egg to adult) is from 3 to 4 weeks in duration. Heavy rainfall soaks heaps of weeds, straw round stockyards, etc., decomposition begins and suitable media for larval development become abundant.

The total number of flies trapped in the 112 24-hour periods was 218,611, of which about 60,000 were *Stomoxys* spp.; the number taken during the entire period, *i.e.*, including the catches on days 2 to 7 in each week, was probably about half a million. The most abundant species were *Stomoxys nigra*, *S. calcitrans*, *Musca d. vicini* and *Chrysomyia putoria*, Wied., the last-named species formed about 9 per cent. of the total non-biting fly population. Seven *Glossina palpalis*, R.-D.,

were seen on the strands, although the nearest river was just under 400 yards from the pig pens; one of these flies was taken in the middle of the dry season (5th January, 1944) and the remainder between May and October. This observation was of some practical importance as the exercise yard of a herd of zebu cattle, a breed susceptible to trypanosomiasis, adjoined the pig pens. After the discovery of *Glossina,* exercise was restricted to the hour following dawn; during the rest of the day the beasts were kept in a flyproof byre.

Time of trapping experiment—Stomoxys *spp.*

Twenty strands were suspended in two pig pens at 09.00 hours on 29th October, 1942, counts were made at hourly intervals until 18.00 hours and at 07.00 and 09.00 hours on 30th October. The results are shown in Table IV.

TABLE IV.

Period of trapping	Number of *Stomoxys* caught	Period of trapping	Number of *Stomoxys* caught
29th Oct.		29th Oct.	
9 to 10 hrs.	31	15 to 16 hrs....	84
10 to 11 hrs.	85	16 to 17 hrs....	187
11 to 12 hrs.	45	17 to 18 hrs....	260
12 to 13 hrs.	84	18 hrs. to 7 hrs. on 30th Oct. (13 hrs.)	... 90
13 to 14 hrs.	73	7 hrs. to 9 hrs.	110
14 to 15 hrs.	72		

It will be seen that about 40 per cent. of the 1,121 *Stomoxys* trapped were taken between 16.00 and 18.00 hours.

Fly distribution in the pig pens.

Table V shows the distribution of *Stomoxys* and non-biting flies in the 12 pens during three six-weekly periods between 10th August and 13th December, 1944. Two wires per pen were used for the study of fly distribution.

TABLE V.

Six weeks ending	Number of flies caught	Percentage of flies in pen					
		1	2	3	4	5	6
		Stomoxys spp.					
20th Sept.	777	3	8	21	23	22	23
1st Nov.	845	3	9	25	24	18	21
13th Dec.	175	5	9	14	15	19	38
		Non-biting flies					
20th Sept.	787	5	13	21	21	18	22
1st Nov.	681	8	10	22	26	18	16
13th Dec.	380	9	13	22	24	14	18

		Stomoxys spp.					
20th Sept.	1,052	12	15	18	24	21	10
1st Nov.	1,228	12	9	23½	23½	22½	9½
13th Dec.	311	7½	7	22½	28	17	18
		Non-biting flies					
20th Sept.	1,253	11	11	23	28	15	12
1st Nov.	1,109	13	10½	19	24½	21	12
13th Dec.	381	11	9½	29	25	10½	15

It will be seen that the distribution of *Stomoxys* and non-biting flies was very similar. Pens 1, 2, 7 and 8 were used for farrowing and contained litters of piglings born between 3rd and 24th June, 1944; pens 3 and 9 were occupied by young pigs born on 10th April and 14th May respectively; whilst the remaining six pens contained large animals, none of which was less than 8 months old at the beginning of the experimental period.

Hornby and Bailey (3) say that attractiveness to flies has a mathematical relation to the size of the animal, whilst McCall (4) noticed that active native cattle appeared able to keep themselves comparatively free from the attacks of *Stomoxys*. The young pigs in the four farrowing pens were very active and it is not possible to decide whether their activity or small size (or a combination of both factors) was responsible for their comparative freedom from *Stomoxys*. The relatively small infestation in pen 12 was probably due to its proximity to an office, which people were constantly entering or leaving.

There did not appear to be any relationship between *Stomoxys* infestation and the number of pigs per pen. In 1942, it was noticed that pigs with sores on their bodies were especially attractive to *S. nigra*; none of the pigs in the period under review had sores.

It was noticed that at certain times of the year flies were more abundant in the pens with a southern aspect than in those with a northern aspect; at other times the position was reversed. These data are summarised in Table VI. S. stands for south-facing, and N. for north-facing.

TABLE VI.

Period	Number of counts			Number of flies in	
	Total	S.>N.	S.<N.	6 S. pens	6 N. pens
28th Oct., 1942 to 5th May, 1943 ...	28	26	2	26,912	18,469
12th May to 24th Nov., 1943	29	4	25	24,850	34,289
1st Dec., 1943 to 12th April, 1944 ...	20	11	9	9,174	8,942
19th April to 29th Nov., 1944	33	6	27	40,015	54,680
6th Dec. to 13th Dec., 1944	2	2	0	710	570
Total	112	49	63	101,661	116,950

It will be seen that during the period when *Stomoxys* is prevalent (May to November) the north-facing pens are more heavily infested than those facing south. An examination of the results of 24 counts between 7th June and 15th November, 1944, showed that of 36,225 *Stomoxys* trapped 45 per cent. were in the S. pens and 55 per cent. in the N. pens, whilst the corresponding figures for 37,725 non-biting flies were 41 per cent. and 59 per cent. It is evident that the presence of *Stomoxys* was not the primary cause of the greater infestation of the north-facing pens at this period; in fact, the preference for the N. pens became apparent during the six counts made between 19th April and 31st May, 1944, when only 340 *Stomoxys* were trapped. Of the 15,035 non-biting flies taken in these counts 65 per cent. were in the N. pens. At Ibadan (Lat. 7° 22′ N.) the sun is overhead on about 9th April and 4th September and its path lies to the north between those dates. In Table IV it was shown that about 40 per cent. of the *Stomoxys* trapped in a 24-hour period were taken between 16.00 and 18.00 hours; in the evening at times when the sun is to the north, the S. pens are in shadow and there is no doubt that this factor is partly responsible for these variations in the distribution of the fly population. Another factor is the direction of the prevailing wind, the greater number of flies occurred in the row of pens sheltered from the prevailing wind. A summary of the daily wind directions is given in Table VII.

TABLE VII.

Period	No. of days	Percentage of days on which wind was blowing from		
		Quadrant N.E. to N.W.	Quadrant S.E. to S.W.	Other directions
24th Oct., 1942 to 7th May, 1943	196	53	42	5
8th May to 19th Nov., 1943 ...	196	27·5	70	2·5
20th Nov., 1943 to 7th April, 1944	140	70	27	3
8th April to 17th Nov., 1944...	224	34	63	3
18th Nov. to 15th Dec., 1944	28	86	14	0

Trapping data.

Unlike the kitchens, the smallest catch occurred on the central wires in the row. In each pen, wires 1 to 6 were opposite the half-wall and wires 7 to 10 over the door leading into the inner pen. The percentage of flies trapped on each wire during the 52 weeks between 22nd October, 1942 and 20th October, 1943, is shown in Table VIII.

TABLE VIII.

—	Total no. of flies caught	Percentage of flies on wire No.									
		1	2	3	4	5	6	7	8	9	10
6 S. pens	50,455	11·7	11·5	9·6	9·4	8·6	8·6	9·0	9·3	11·0	11·3
6 N. pens	50,662	11·7	10·5	9·7	8·4	7·8	8·8	9·9	10·6	11·45	11·15

The above figures refer both to *Stomoxys* spp. and non-biting flies; it was found that the distribution of the two groups on the wires was similar. A favourite resting place for flies was the walls separating the outer yards of the pens from one another; it seems probable that this factor was responsible for the bigger catches on the wires at each end of the row.

A certain amount of trouble was experienced with small mammals, probably mice, which attempted to feed on the trapped flies during the night. They became attached to some of the strands and, in their efforts to escape, left the affected strands stuck to the grass thatch of the roof. It was thought that the use of wires would overcome this difficulty, but when the wires were hooked over the horizontal string a few were removed by the mammals. It is therefore advisable, in pig pens, to tie the wires to the string.

Bionomic Data.

(*a*) *Stomoxys* spp.

In spite of the fact that adults of *Stomoxys nigra* were about 15 times as numerous as those of *S. calcitrans* in the pig pens and elsewhere on Moor Plantation, the vast majority of the adults bred out from larvae taken in the field belonged to the latter species. To date the writer has been unable to find the reason for this curious fact. Two possible explanations are, firstly, that under laboratory conditions larvae of *nigra* are destroyed by those of *calcitrans* and

secondly that larvae of *nigra* are very susceptible to changes in the humidity of the breeding material. The only occasion on which adults of *nigra* were bred out in numbers was when a large quantity of farmyard manure (containing an unusually high proportion of bedding) from a dairy in Ibadan was placed in a large cage; large numbers of *calcitrans* were bred out from the same material. The farmyard manure had been placed in a shallow trench and covered with soil; vast numbers of both species of *Stomoxys* were present in the vicinity of the dairy.

The following table shows the number of adults of both species bred from larvae in different media.

TABLE IX.

Medium	No. of *calcitrans* adults	No. of *nigra* adults
Heaps of decomposing vegetation ...	37	14
Cow dung in field	13	1
F.Y.M. in cow byres	88	1
F.Y.M. in compost pit	4	0
Mud from cow byre drain	1	0
Slaughter house refuse	2	0

No evidence was obtained that either species breeds in pig manure.

An experiment was carried out in which two heaps of grass and two of dicotyledonous plants were placed (on 19th Nov., 1942) near the heavily infested pig pens. On six days a week one heap of each type was watered thoroughly and the remaining two heaps were moistened with urine from a nearby dairy. Two days after larvae were seen to be present in a heap it was screened with wire gauze. The results of this experiment are shown in Table X.

TABLE X.

Medium	No. of adults bred out		Period during which adults emerged	
	calcitrans	*nigra*	*calcitrans*	*nigra*
Grass—urine	110	9	9th–30th December	15th–26th December
Dicot.—urine	37	4	9th–23rd December	8th–16th December
Grass—water	0	1	...	26th December
Dicot.—water	0	8	...	9th–23rd December

On 31st October, 1942, a heap of grasses of various species and the following dicotyledonous weeds, *Talinum triangulare*, *Ageratum conyzoides* and *Boerhaavia diffusa*, was placed near the pig pens and watered on six days a week. Eight *nigra* adults emerged between 17th and 26th November, and six *calcitrans* adults between 21st and 30th November. If we assume that oviposition occurred on the first day of each experiment, the minimum life cycle (egg to adult) was 19 days for *nigra* and 20 days for *calcitrans* in the first experiment and 17 days and 21 days respectively in the second experiment. In Mauritius (5) the minimum life cycle of *nigra* is 27 days when the eggs are laid on cattle droppings, and the temperature during the pupal period is from 25 to 30° C. (77 to 86° F.). During the experimental period the mean maximum temperature was 90° F. and the mean minimum temperature was 72° F.

In addition to attacking cattle and pigs, both species of *Stomoxys* frequently obtained their meal of blood from the combs of Rhode Island Red cockerels; they were undoubtedly responsible for transmitting fowl pox from bird to bird.

Apart from lizards, the only natural enemy of *S. nigra* observed was an entomogenous fungus (probably *Empusa* sp.) which destroyed large numbers of flies between July and September, 1944.

(*b*) *Musca domestica vicina*, Macq.

The main breeding sites were latrines, trenching grounds, pits containing pig manure and bedding, slaughter house refuse and heaps of rotting food (principally cooked groundnut refuse and palm kernel, guinea corn and cassava meal). Flies were also bred from cattle droppings, manure in sections of cow byres exposed to sunlight, rotting mangoes and grapefruit, rotting spinach (*Amaranthus caudatus*) and grass, pig dung and mud from the edges of drains leading from cow byres and pig pens.

(*c*) *Musca cuthbertsoni*, Patt.

This species was bred from cattle droppings, palm kernel meal lying round the edge of a puddle, mud from the end of a drain leading from the pig pens and farmyard manure (pig dung and bedding) in a field.

(*d*) *Musca gabonensis*, Macq.

On one occasion 39 flies of this species were bred from a heap of cow dung in a field.

(*e*) *Chrysomyia putoria*, Wied.

The principal breeding sites of *C. putoria* were pits containing pig dung and bedding, mud from the end of a pig pen drain, pig manure in a field and palm kernel meal on the edge of a puddle. Eighteen adults were bred from manure in sections of cow byres exposed to sunlight and one from a heap of rotting guinea corn meal.

Summary.

(1) An adhesive made from 3 or 4 parts (according to the temperature) of the coagulated latex of *Carpodinus hirsuta* and 1 part of either shea butter (from *Butyrospermum parkii*) or palm oil (from *Elaeis guineënsis*) was found to be very effective against both house-flies in kitchens and *Stomoxys* spp. in pig pens.

(2) In kitchens, wires (diameter 4 mm.) were treated with the adhesive and suspended over the table on which food was prepared. The wires should be renewed every three or four days when flies are abundant and once a week when the infestation is light.

(3) At Ibadan in 1943, house-flies were abundant from early March to late July; the maximum house-fly infestation of both kitchens and pig pens occurred during the second week of May. The upward trend in adult incidence first became evident in mid-February of both 1943 and 1944 and appeared to be correlated with a rise in temperature at that time.

(4) Ten wires treated with adhesive were suspended under the eaves of each pig pen. Each pen consisted of a covered pen and an open yard divided by a half-wall; a screen made of oil palm fronds was erected above the half-wall with the object of making the inner pen sufficiently dark to deter flies from entering it. About half a million flies (about 27·5 per cent. *Stomoxys* spp.) were trapped in 12 pens in a period of 112 weeks.

(5) *Stomoxys* spp. (principally *S. nigra*, Macq.) were abundant between early June and mid-August in 1943 and between early June and late November in 1944. In 1943 there was a short dry season between 25th July and 12th September, whilst in 1944 there was no break in the rains. There is a marked correlation between rainfall and the incidence of *S. nigra*. Heavy rainfall soaks straw round the stock-yards, heaps of weeds, etc., which decompose and provide suitable media for larval development.

Acknowledgements.

The writer wishes to acknowledge his indebtedness to the Imperial Institute of Entomology for identifying the flies mentioned in this paper, and to Mr. J. West and the Principal of the Government College, Ibadan, for supplying him with meteorological data.

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RETIREMENT OF DR. SHEFFIELD A. NEAVE, C.M.G., O.B.E.

The retirement on 31st July of Dr. Sheffield A. Neave, Director of the Imperial Institute (formerly Bureau) of Entomology since 1942, will be deeply regretted, not only by the Executive Council and Staff of the Institute, but by entomologists throughout the world. He is known personally or by repute to a wide circle of entomologists, many of whom have reason to be grateful to him for sympathetic help and sound advice. He will take with him the best wishes of everyone on his retirement.

Dr. Neave was appointed Assistant Director of the then Bureau of Entomology in 1913 whilst serving in Africa as an Entomologist to the Entomological Research Committee (Tropical Africa). He returned to this country in March, 1914, to take up his duties and continued to fill the position until 31st July, 1942, when he succeeded Sir Guy Marshall as Director. His long experience of 33 years on the staff has been wholeheartedly devoted to building up the Institute on the principles originally laid down.

Dr. Neave's outstanding service has been the development of the Institute's Publication Office of which he has been in charge almost since its inception. The principal publication issued by this office is the *Review of Applied Entomology* which first appeared in 1913 and was taken over by Dr. Neave in 1914. It is no exaggeration to say that the " Review " is regarded to-day by economic entomologists, wherever they may be, as the one work that is absolutely indispensable to them. Apart from the many appreciations that have been received from all quarters, the steadily increasing circulation bears testimony to the high value placed on it by entomologists, not only of the British Commonwealth of Nations, but of foreign countries.

In 1939–40 Dr. Neave published his *Nomenclator Zoologicus* in four volumes. This great and painstaking work, containing the names and references of some 100,000 genera of insects, is a standard reference work of the greatest importance to every systematic worker.

The " Review " and the " Nomenclator " represent a major contribution to the advancement of entomological knowledge and they will be a constant reminder for many years to come of Dr. Neave's great services to entomology.

For the past four years Dr. Neave, as Director, has supervised the *Insecta* part of the *Zoological Record* and edited the *Bulletin of Entomological Research* in addition to all his other duties. This period of the later war years and first post-war years has been one of considerable difficulty and the successful manner in which it has been negotiated must be attributed to his ability and wise guidance.

Dr. Neave is being succeeded by Dr. W. J. Hall, M.C., D.Sc., who joined the staff of the Institute in 1943 after 23 years' service in Egypt and Southern Rhodesia, and was appointed Assistant Director in 1944. The latter's place as Assistant Director is being filled by Dr. T. H. C. Taylor, D.Sc., who joined the staff in November, 1944, after 19 years' service in Fiji and Uganda.

J. G. ROBERTSON, *Lt.-Col.*
Chairman of the Executive Council of the
Imperial Agricultural Bureaux.

July, 1946.

OBSERVATIONS ON THE YELLOW TEA-MITE *HEMITARSONEMUS LATUS* (BANKS) EWING.

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The yellow tea-mite was first described by Green in 1890 under the name of *Acarus translucens*. Later, he became aware that that name had been utilised by Nietner in 1861 for a mite which occurred amongst colonies of *Lecanium coffeae*, the "brown bug" of coffee. Consequently in 1900 he republished the description renaming the mite *Tarsonymus translucens*, by which name it has since been known to entomologists working with tea pests. The genus *Tarsonemus* Canestrini and Fanzago (1876) was certainly intended, but Green's misspelling of it was continued for many years in the tea literature of Ceylon, India and the Dutch East Indies, *e.g.* Rutherford (1913) and Bernard and Kerbosch (1918).

In 1904 Banks described a mite, which causes galls on the main shoots of mango plants growing in greenhouses in the U.S.A., under the name *Tarsonemus latus*. It has since been collected from numerous other plants in the U.S.A. His figure of the male (Banks 1915, p. 107) shows a broad, truncate hind-end and does not suggest Green's *T. translucens*, the posterior segments of which are tail-like. Banks was aware of Green's species though he erroneously refers to it as *T. pellucens*, Green (p. 108).

Ewing (1939) reviewed the mites belonging to the sub-family Tarsoneminae and established the synonymy of *Acarus* (*Tarsonemus*) *translucens*, Green, and *T. latus*, Banks. He also erected a new genus, *Hemitarsonemus*, for this and congeneric species, but made *T. trepidariorum*, Warburton, the type "because of the confusion that has resulted in regard to the status of the *Acarus translucens* Green". Ewing states that he had been unable to see the original (1890) description by Green, and it is probable that he was also unaware that Green had renamed and redescribed the mite as *Tarsonymus translucens* in 1900 as he offers no comment on the status of that name. I am indebted to Prof. D. R. R. Burt of Ceylon University and Dr. S. A. Neave, Director of the Imperial Institute of Entomology, for opinions that Article 36 of the International Code invalidates further use of Green's specific name. The yellow tea-mite should, therefore, be known in future by Ewing's combination *Hemitarsonemus latus* (Banks) Ewing.

Rutherford (1913) wrote of the yellow tea-mite, "Frequently a male may be seen carrying along behind it, supported on the apex of the abdomen a six-legged, whitish, smooth, immobile body whose long axis is placed at right angles to its own. Occasionally one sees a male pounce on another male that is carrying such a burden and obviously try to wrest it from it. One such, failing in this, was seen to examine several of the unattached, white, sedentary mites but it rejected them all. Are these bodies female pupae about to moult into adults?"

The writer has not seen an answer to that question, but as the following observations will show, the answer is "Yes".

The yellow tea-mite occurs on both sides, though most abundantly on the underside, of very young tea leaves, the two or three nearest the unopened bud. As the shoot grows, the colonies desert the older leaves and move to the young expanding leaves and terminal bud.

The eggs adhere firmly to the leaf. They are oblong oval in outline and measure about 0·115 by 0·70 mm.; they are flattened and smooth on the ventral surface, but the upper surface is beautifully marked with five or six rows of round, white tubercles, the longest row having about eight tubercles. The eggs are relatively very large, being about half the size of the adult that lays them.

The adult female is of a light, translucent, yellowish-green colour with a distinct dusky white band along the mid-dorsal region. They have been described as very active and restless, but their movements when compared with males appear very leisurely.

The larvae are much smaller and very sluggish, pale yellow or greenish, with a whitish stripe along the middle of the back. Before becoming adult, the larva ceases to feed and remains quiescent, with its body extended to its full length. This latter stage may for convenience be termed the pupa, although no moult has been observed between the slow moving stage and this quiescent one.

The male is much smaller but much more active than the female ; he seems to spend his whole life running aimlessly over the leaf. The posterior end of his body is somewhat tail-like, each of the last segments being narrower than the preceding one. Near the apex on the ventral side is a relatively large sucker-like organ. Ewing describes the genital papilla as " usually appearing truncate at apex ; when dilators are expanded, papilla may be fanlike". The writer prefers the term " sucker-like " to " fan-like " to describe this organ, as it is used as a sucker to hold and carry the pupa in the manner described by Rutherford. He normally holds his hind-end somewhat high, but when carrying a pupa, his " tail " is almost vertical so that the pupa is held well above his back. His hindmost legs are the stoutest and look as though they might well be used for clasping, yet he neither uses them for locomotion nor to grip and hold the pupa, even when attacked by another male attempting to deprive him of it.

After watching a colony for a time, giving particular attention to the males, one comes to the conclusion that each burdenless male is searching for something, as though playing a game of blind man's buff. He can neither see nor scent accurately the position of the object of his search. He runs about apparently aimlessly and occasionally bumps into something. It may be a female or a larva. He stops and touches the object with his forelegs and then runs off again. He may pass very close to a pupa, but unless it is directly in his path, so that he stumbles against it, he appears unconscious of its presence. Yet if he encounters another male carrying a pupa, he immediately attempts to attach his hind-end to it. If successful, a tussle ensues, until one carries away the trophy victoriously. The loser never pursues ; he appears ignorant of the direction in which the victor has gone.

Particular pupae are evidently the sought-for prizes. As noted by Rutherford, a male may examine what appear to the observer suitable pupae, yet reject them. When, however, a male locates an acceptable pupa, he uses his tail as a lever to free it from the leaf, and then scuttles away rapidly with the pupa adhering to his tail, held well above his body. Why so many pupae prove unacceptable is unknown, but it seems probable, as the following experiment suggests, that only female pupae are selected and that these must have reached a certain stage of development before they become attractive.

Experiment 1.

Twelve males, each carrying a pupa, were transferred to fresh, young tea shoots, maintained with their cut ends in water. One male was placed on each shoot, which otherwise was free of mites. The following day each shoot was found to carry one male and one adult female mite. This experiment definitely proves that the object carried by each male is a pupa due shortly to become adult, but it does not show conclusively that only female pupae are carried. Much depends upon the sex ratio. If that ratio approximates 12 : 1 it would not be surprising that all 12 pupae should be female, even if in fact male pupae are carried. This question will later be considered further.

As already stated, all 12 pupae had become adult females on the day following their removal to fresh tea shoots. On that day the males were destroyed but the females were left on the leaves. On the following day, *i.e.* on the completion of the first day of the mites' adult life, each shoot was found to carry eggs, varying in number from 1 to 4. The females were then removed, each to a fresh shoot, free of mites and eggs. This procedure was followed daily so long as the females lived, to enable daily records to be kept of each female's egg-laying. In order to reduce the area to be searched, the terminal bud and all extraneous leaves were removed, leaving one leaf only—the first or second from the terminal bud. The apical half of this leaf can also be removed without detriment. The shoots were kept on the laboratory table, without cages of any sort, as it had been found that the females do not tend to wander from the leaf on which they are placed. It may be mentioned here that males behave differently and wander more; they will move from one leaf to another, and under the above conditions are soon lost.

Two of the 12 females were lost during the second day of their adult life; the other 10 were maintained on fresh leaves until they died. The first was found dead on the sixth day of her adult life, and the last died on the fifteenth day. The average adult life was 10 days. The largest number of eggs laid by one female was 56 in 12 days, giving an average of 4·7 eggs per day; on each of four days she laid as many as six eggs. The smallest number of eggs laid was 10, by a female which died on the sixth day, giving an average of two eggs per laying day. The highest average obtained was 4·8 eggs per laying day, from a mite which was found dead on the eighth day, having laid eggs for seven consecutive days. On the first day, an average of 2·5 eggs per female was laid; that number increased to 4·3 on the second day and remained above 4 till the eighth day, after which it gradually decreased to 2·0 on the thirteenth and fourteenth days.

In all, 363 eggs were laid by the 10 females and the development of 197 of them was followed to the adult stage. They proved to be 158 females and 39 males, giving a sex ratio of 4 : 1. Since unfertilised females give rise to male offspring only, as will be shown later, the presence of females in this population affords clear proof that at least 80 per cent. of the parent females were fertilised. More probably all were mated. As the male parents were removed within 24 hours of the pupae becoming adult, it is evident that females which are carried as pupae are normally mated within the first few hours of their adult lives, most probably as soon as they become adult.

If we accept the determined sex ratio (4 : 1) as fairly representative of a population derived from fertilised females only, the probability that 12 pupae selected entirely at random from such a population will all be females, is 6·8 per cent. A sample of 14, all females, would be necessary to reduce the probability to just below 5 per cent. Males, however, do not select pupae at random; they appear to make a careful choice. That fact materially increases the probability that female pupae only are carried.

If, however, our estimate of the sex ratio is too wide for a population such as occurs in the field, because of the presence of offspring from unfertilised females, a closing of the ratio to 3·5 : 1 would be sufficient to reduce the probability of collecting females only in a sample of 12, to just below 5 per cent. This observation raises a question regarding the likelihood of unfertilised females occurring in a normal field population.

If the sex ratio of a population derived from fertilised females is 4 : 1 it will be evident that, if all females are to be mated, each male must serve four females. A male can carry only one pupa at a time, and if he wanders with it far from the colony, because the leaf is becoming too old or for other reasons, he is unlikely to return to that colony. The desertion of a colony by the males would tend to cause an increase in the number of unfertilised females. Their young, being males, would

also tend to depart with or without a pupa. Older leaves would thus ultimately be depleted of mites, which from general observation is known to be the case. This argument suggests that a population, as it occurs in the field, probably includes offspring of unfertilised females, and that in consequence the sex ratio is narrower than that determined from fertilised females only.

Another question also arises. Can a male mate with a female at a time later than the first few hours of her adult life ? The following experiment was designed to answer this question. It also demonstrates that an unmated female produces male young only, and that a fertilised female has offspring of both sexes.

Experiment 2.

Female yellow mites collected from the field were placed on suitable fresh tea leaves, one female per leaf, and on the following day the shoots were examined for eggs. Those which carried one egg only were retained and the females were removed. In due course the eggs hatched, and the larvae became adults. Of these, the leaves carrying males were discarded. In this way, adult females which had never come into contact with males were obtained. Egg-laying records were kept, and the young were maintained till maturity.

The number of eggs laid was smaller than that observed in the first experiment. During the first seven days, all females laid eggs daily, but none laid at a greater average rate than 2·5 per day. The average laying rate over this period was 2·0 per day.

The resulting adults were all males. It must be stated, however, that not all the adult offspring were seen. The presence of the pupa was checked on the day preceding that on which adult emergence was expected, but of 128 eggs laid and pupae formed by the 11 mites, only 66 adults were accounted for, and they were all males. Not one young female was found.

On the eighth day of their adult lives, four of the parent mites were supplied with males. Two or three were placed on the leaf with each female, and, as a general rule, more males had to be supplied daily owing to their tendency to wander. The four females may be designated A, B, C and D, and their performances discussed separately.

Female A lived for four days after males were provided, during which time she laid 13 eggs. From these 9 males were obtained, but 4 pupae were unaccounted for ; presumably the latter were also males. Previously, this female had laid at the rate of two eggs per day, but as there is no evidence here of mating, it seems unlikely that the increased rate of egg-laying can be due merely to the presence of a male.

Female B was lost on the sixth day after males were supplied, but otherwise her record was similar to that of Female A. She laid 13 eggs ; 9 males were recovered and 4 were unaccounted for. Her previous rate of egg-laying was 2·1 eggs per day.

Female C also lived for four days and laid 13 eggs. These gave rise to 12 females and 1 male. Her previous laying rate while producing males only was 1·9 eggs per day. On the day males were first introduced, she laid four eggs, of which only one gave rise to a male. Eggs laid later all became females.

Female D lived for eight days and laid 33 eggs, of which 27 developed into females, 4 were males and 2 were unaccounted for. Her previous egg-laying rate had been 2·4 eggs per day. On the day males were first introduced she laid 5 eggs, of which 2 developed into males and 3 into females. The other two males came from eggs laid on the fourth and sixth days ; the two unaccounted eggs were laid on the fifth and sixth days.

This experiment shows that unmated females produce male offspring only, and that although mating normally occurs in the first few hours of the adult female's life as shown in Experiment 1, it may occur later also. The record of Female C suggests that all eggs laid after the day on which mating occurs give rise to female offspring ; that conclusion is, however, clearly contradicted by the record of Female D. Again, the record of Female D suggests that mating increased the laying rate, as her record after mating not only shows a marked increase but also compares very favourably with those obtained in Experiment 1. It should be noted, however, that the laying records of all four females improved after males were supplied, so it seems more probable that such improvement was due more to a favourable change in the environmental conditions, which were not controlled, than to the presence of males.

Life-Cycle.

Little can be added to what is already known about the life-cycle of this mite. The eggs hatch after two or three days, and the mite becomes adult two or three days later. The life-cycle, under conditions that exist in March, April and May in the Tea Research Institute's laboratory at St. Coombs occupies from four to six days, i.e. about five days.

General Observations.

Green (1890), in his original description of *Acarus translucens* stated : "It (the young mite) seems to undergo only one moult before assuming the perfect stage". One might expect two moults, one during the larval stage when the larva becomes quiescent, and the second on becoming adult ; but the writer has neither observed a moult nor seen cast skins. Admittedly, cast skins may be difficult to locate even in experiments such as these, in which leaves have been searched regularly with the aid of a binocular microscope.

Mention has already been made of the relatively large tuberculate eggs, nearly half as large as the female body, that a female may lay as many as six eggs per day, and that a common laying rate is four per day. A female, therefore, may deposit as eggs, a volume of about two or three times her own total bulk, daily. Eggs are never clearly visible in the body, but the ovaries obviously could not contain two full-size eggs at the same time. Egg enlargement must therefore be very rapid, but whether it occurs inside or outside the body is unknown. Although considerable time has been spent observing colonies of this mite, the act of oviposition has not been seen by the writer or his assistant, nor have undersized eggs been observed, as might be expected if the egg did not become full-sized till a short time after deposition.

The curious habit of the male in carrying away female pupae helps to account for the known distribution of this mite in the tea bush. Females, as shown by the ease with which they can be maintained on particular leaves of a shoot, do not tend to wander from the leaf on which they are placed. Larvae are quite sluggish and almost invariably pupate on the leaf on which they fed. Yet the colonies disappear from leaves as they grow older, and are always found at the terminal bud and on the young leaves immediately below it. The male when carrying a pupa seems to wander rather aimlessly, but these facts suggests a general tendency for him to migrate towards the terminal bud and younger leaves. The presence of young fertile females at or near the terminal bud and the disappearance of colonies as the leaves age may thus be accounted for. The male may travel a considerable distance, to another shoot or to an adjoining bush, but he obviously tends to deposit his burden on the youngest leaves. The choice of a suitable place for egg laying is thus made by the male.

Other methods of dispersal, *e.g.* wind, are also operative, but the male *Hemitarsonemus latus* evidently plays a more active part in distributing this species than has been noted for other mites.

Acknowledgement.

My thanks are tendered to my laboratory assistant, Mr. D. J. W. Ranaweera, for his patience and skill in handling delicate mites and transferring them from leaf to leaf without injury, and so making these observations possible.

Summary.

The yellow tea-mite should in future be known as *Hemitarsonemus latus* (Banks) Ewing.

The males have a curious habit of carrying female pupae to younger leaves. The pupa is held above the male's body by means of a sucker-like organ near the tip of his tail-like, posterior terminus. Thus the male plays an active part in distributing the pest.

Mating has not been observed, but normally it occurs as soon as the female becomes adult. It may also occur later in her life.

Unfertilised females give rise to male offspring only, but mated females have mixed families.

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REPELLENCY OF PYRETHRUM AND LETHANE SPRAYS TO MOSQUITOS.

By MAJOR C. R. RIBBANDS, R.A.M.C.

Introduction.

These experiments were commenced because it was necessary to measure the repellent effect of certain sprays in order to interpret the results of another series of experiments. The repellent effects which were demonstrated might have considerable anti-malarial uses in certain circumstances. The results confirm and amplify the conclusions of Swellengrebel & de Buck (1938), who stated that spraying of houses with pyrethrum, to kill *Anopheles maculipennis*, Mg., had the additional effect of a repellent, provided that the insecticide was lavishly applied (at the rate of nearly a pint per house), and of Senior White & others (1945), who have recently shown that daily spraying of houses with pyrethrum in kerosene causes a definite repellence to the entry of *A. minimus*, Theo.

Methods.

All these experiments were conducted on Hilika Tea Estate, Doom Dooma, Assam, by the courtesy of the Manager of that estate and the Superintendent and the Medical Officer of the Assam Frontier Tea Company, Ltd. All the catches were made by personnel of No. 2 Entomological Field Unit, R.A.M.C., aided by coolie labour, and the same catching technique was used throughout; sheets were used to cover the floor and furniture of coolie huts, the rooms were sprayed with insecticide and the dead mosquitos recovered from the sheets. The huts were scattered round the garden perimeter, and most of them had mud walls and a thatched roof. They were windowless and open at their eaves.

The first series of experiments compared the extent and persistence of the repellent effects of 0·1 per cent. pyrethrum in kerosene with those of aerosol bombs (containing 0·4 per cent. pyrethrum and 8 per cent. sesame oil in Freon 12) and of 10 per cent. Lethane 384 (50 per cent. *n*-butyl carbitol thiocyanate in paraffin) in kerosene. A second series investigated the short-term repellency of Lethane in kerosene, and the last experiment demonstrated pyrethrum repellency in night catches.

The huts were usually of standard size and contained two rooms, each about 10 ft. by 10 ft. The theoretical required dose would therefore be 20 c.c. 0·1 per cent. pyrethrum per hut. Such doses have been found to be insufficient for complete kills in such huts, and the doses actually used averaged 50 c.c. 0·1 per cent. pyrethrum in kerosene (=0·05 c.c. pyrethrins), or 50 seconds of aerosol spraying (=0·075 c.c. pyrethrins), or 25 c.c. of 10 per cent. Lethane 384 in kerosene.

The mosquito population herein described as *Anopheles minimus* was really a mixed population of the group *Myzomyia*, comprising about 75 per cent. *A. minimus*, with the rest mainly *A. varuna* Iyen., and *A. fluviatilis* James.

The experiments were made between 16th July and 10th October, 1945. This was during the monsoon season, and climate showed no great variations. The absolute maximum and minimum temperatures were 95 and 73° F. respectively, and the averages were 87 and 77° F. Rainfall averaged 13 inches per month and relative humidity was about 90 per cent. These statistics are given because it is possible that repellency effects vary with climate, which may affect evaporation rates.

Groups of three huts were selected and sprayed before the beginning of the experiment, and then in rotation as follows:—

Day	3	4	5	8	9	10	13	14	15	18	19	20	23	24	25	28	29	30
	A	B	A	A	C	A	B	C	A	C	B	A	C	A	A	B	A	A
			B			B			B			B			B			B
			C			C			C			C			C			C

At the end, therefore, each hut had been sprayed ten times, two sprayings having been made at each of the intervals 1, 2, 3, 4 and 5 days after a previous spraying.

This procedure eliminated to a considerable extent the obscuring effects of large short-term fluctuations in mosquito numbers, which have previously been demonstrated in other species and are now known to occur in those in question (Ribbands, 1946a), because the catches on the first, second and fifth days after spraying were all made on the same days, although in different huts. These three results are therefore more readily comparable than those after three and four days, which had been made two and one days before them, respectively.

All sprayings were done in the afternoon, between 2 p.m. and 4.30 p.m.

The results are given in tables which schedule the catch from each hut after each pair of sprayings. The extent of the repellency is shown by expressing the catch after each interval as a percentage of the same catch after the five-day interval, when the repellent effect is assumed to be negligible (a conservative assumption which may not be justified concerning *A. minimus*, in certain instances). Gravid

TABLE I

Extent and Persistence of Repellency, 0·1% Pyrethrum Spray

Hut Prefix	Numbers of *A. minimus*														
	Non-gravid Females.					Gravid Females.					Males.				
	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day	5th day
A	0	1	0	1	14	0	0	0	2	2	0	0	0	1	2
B	2	0	1	0	3	2	0	0	0	2	0	0	0	0	1
C	0	0	0	3	4	0	0	0	1	0	0	1	0	1	0
D	2	3	2	8	8	0	0	0	0	2	0	0	0	0	2
E	0	2	0	0	2	0	0	0	0	2	0	0	0	0	0
F	2	5	7	14	20	0	0	2	7	9	1	0	3	7	10
G	0	2	4	14	6	0	0	0	0	2	0	0	0	0	1
H	1	13	13	8	10	0	2	3	0	4	0	0	3	0	4
J	3	15	15	26	45	0	1	2	12	17	0	1	0	0	0
Total ..	10	41	42	74	112	2	3	7	22	40	1	2	6	9	20
Percentage of catch on fifth day ..	9%	37%	38%	66%	100%	5%	8%	18%	55%	100%	5%	10%	30%	45%	100%

Hut Prefix	Numbers of Culicines.										Numbers of *A. vagus*.				
	Female.					Male.					(Too few for segregation of sexes).				
A	15	11	18	14	17	9	2	0	10	12	0	0	0	1	2
B	6	12	13	34	15	2	6	2	16	15	0	2	3	4	2
C	4	11	3	28	12	4	9	3	24	13	4	0	0	3	3
D	9	6	4	16	18	4	5	14	14	12	1	0	0	0	4
E	3	12	9	2	6	4	7	5	0	3	1	2	2	2	1
F	5	33	27	21	43	4	28	25	13	33	1	1	0	1	3
G	7	4	6	10	24	2	1	1	11	7	1	2	2	9	4
H	10	10	44	72	18	3	8	18	20	7	1	3	31	2	6
J	8	55	26	55	40	11	85	27	38	49	2	7	9	5	11
Total ..	67	154	150	252	193	43	151	95	146	151	11	17	47	27	36
Percentage of catch on fifth day ..	35%	80%	78%	132%	100%	28%	100%	63%	97%	100%	31%	47%	131%	75%	100%

A. minimus are mainly mosquitos that have fed and remained within the same hut for a second night, and they are therefore listed separately in the tables; their results should exhibit a partial time lag.

Extent and Persistence of Repellency after Spraying with 0.1 per cent. Pyrethrum in Kerosene.

Nine huts, in three groups of three, were used for this experiment. The results are presented in Table I. The sprayings led to considerable reductions in the numbers of all categories of *A. minimus*, and the effect persisted for at least four days. Reduction of infestation of fed *A. minimus* by 90 per cent. after the first night and 60 per cent. after the second night was the most important result obtained. Males were slightly more sensitive than females, both in the case of *A. minimus* and among Culicines. *A. vagus* Dön., were not so sensitive to the repellent as *A. minimus*, but were rather more sensitive than Culicines, especially on the second night.

Extent and Persistence of Repellency after Spraying with a Pyrethrum Aerosol.

Six huts, in two groups of three, were used, and the results are set out in Table II. In all categories the results were consistent with those obtained by pyrethrum flitting, but the repellency engendered by the aerosol was slightly less. Males of *A. vagus* were more sensitive than females.

TABLE II.

Extent and Persistence of Repellency, Pyrethrum-Freon Aerosol.

Hut Prefix.	Numbers of *A. minimus*. Fed Females. 1st day	2nd day	3rd day	4th day	5th day	Gravid Females. 1st day	2nd day	3rd day	4th day	5th day	Males. 1st day	2nd day	3rd day	4th day	5th day
K	2	0	0	2	3	0	0	0	0	3	0	0	0	2	3
L	2	2	9	57	19	0	0	2	3	0	0	0	1	2	0
M	2	3	5	1	2	0	1	0	1	0	0	1	0	0	0
N	1	1	0	8	27	0	0	0	1	2	0	0	0	0	0
O	0	2	2	1	4	0	0	4	2	0	0	0	1	0	0
P	1	26	10	50	28	0	2	7	26	18	0	0	0	1	2
Total ..	8	34	26	119	83	0	3	13	33	23	0	1	2	5	5
Percentage of catch of fifth day ..	10%	41%	31%	143%	100%	0%	13%	56%	143%	100%	0%	20%	40%	100%	100%

Hut Prefix.	*Culex*. (Numbers too few for segregation of sexes).					Numbers of *A. vagus*. Female.					Male.				
K	3	2	0	2	3	3	2	0	2	4	0	0	0	0	3
L	1	2	5	13	8	8	1	2	13	14	2	0	0	6	1
M	0	0	0	1	0	2	3	2	8	3	0	1	0	2	0
N	2	3	0	1	5	5	6	0	0	19	1	0	0	0	5
O	1	0	1	0	1	1	2	0	6	2	0	1	0	2	0
P	0	4	1	10	2	1	34	6	42	22	0	2	1	1	2
Total ..	7	11	7	27	19	20	48	10	71	64	3	4	1	11	11
Percentage of catch on fifth day ..	37%	58%	37%	143%	100%	31%	75%	16%	110%	100%	27%	36%	9%	100%	100%

It is interesting to note the lessened repellency with the aerosol, despite the fact that the pyrethrin content of this treatment was 50 per cent. greater than that of the pyrethrum in kerosene. This was probably due to the much greater loss of pyrethrum through air currents which act upon the finely dispersed aerosol.

Extent and Persistence of Repellency after Spraying with 10 per cent. Lethane 384 in Kerosene.

Only one group of huts was used for this experiment, the results of which are set out in Table III. There is evidence of some repellency to both *A. minimus*, Culicines, and male *A. vagus* after the first night, but that this effect had worn off before the second night. Female *A. vagus* showed no evidence of repellency on the first night.

TABLE III.

Extent and Persistence of Repellency, Lethane-kerosene Spray.

Hut Prefix.	Numbers of *A. minimus*.														
	Fed Females.					Gravid Females.					Males.				
	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day	5th day	1st day	2nd day	3rd day	4th day	5th day
Q R S	8 6 8	14 10 15	10 2 17	20 4 18	12 20 6	0 0 1	0 16 1	2 2 6	2 2 7	0 0 4	0 0 1	0 0 4	0 2 7	0 0 0	0 6 0
Total ..	22	39	29	42	38	1	17	10	11	4	1	4	9	0	6
Percentage of catch on fifth day ..	58%	103%	76%	110%	100%	No conclusions.									

Hut Prefix.	*Culex.* Male and female.					Numbers of *A. vagus*.									
						Female.					Male.				
Q R S	5 3 6	2 23 1	21 15 7	6 5 5	4 9 13	19 15 20	22 26 7	19 20 11	4 29 20	6 18 22	6 10 4	3 7 6	11 9 10	3 13 6	4 16 18
Total ..	14	26	43	16	26	54	55	60	53	46	20	16	30	22	38
Percentage of catch on fifth day ..	% 54	% 100	% 166	% 61	% 100	% 117	% 120	% 130	% 115	% 100	% 53	% 42	% 79	% 58	% 100

Further Experiments on Extent of Repellency of Lethane 384 in Kerosene.

The above results caused me to select the Lethane spray for a series of experiments which involved repeated catches, and therefore a more precise estimate of the repellency resulting from Lethane spraying was necessary. Seven huts heavily infested with *A. minimus* were chosen. They were sprayed, in pairs or singly, on the days listed in Table IV, the sprayings being arranged so that each hut was sprayed on two successive mornings (at about 9 a.m.), and then left unsprayed for three days before the process was repeated.

TABLE IV.

Effects of Lethane Kerosene Spray on *A. minimus*.

Date.	Huts.	Non-Gravid Females.					Gravid Females.					Males.				
		First morning.	Expectation second morning (69% of first).	Second morning.	% of expectation.	Average of %.	First morning.	Expectation second morning (69% of first).	Second morning.	% of expectation.	Average of %.	First morning.	Expectation second morning (69% of first).	Second morning.	% of expectation.	Average of %.
3–4.x.	T, U	350	242	83	34%		73	50	1	2%		12	8	9	110%	
4–5.x.	V	114	79	42	53%		31	21	4	20%		1	1	2	200%	
5–6.x.	W, X	306	212	88	42%		61	42	4	10%		18	12	23	192%	
6–7.x.	Y, Z	132	91	59	65%	53%	26	18	3	17%	13%	14	10	10	100%	117%
7–8.x.	T, U	52	36	27	75%		1	1	0	0%		2	1	2	200%	
8–9.x.	V	50	35	4	11%		11	8	1	12%		1	1	0	0%	
9–10.x.	W, X	79	54	28	89%		8	6	2	33%		15	10	2	20%	
Total ..		1,083	748	351	47%		211	145	15	10%		63	43	48	112%	

The results are complicated by the fact that unfavourable weather was causing a rapid decline in the mosquito population at that time. The extent of this decline was measured by comparing the catches in huts T–X on their first spraying with the catches obtained in the same huts four days later. On the earlier occasion, 966 *A. minimus* were obtained and only 219 on the later one. This is equivalent to an average reduction of 31 per cent. per day (966, 666, 460, 317, 218),and therefore, in the absence of any repellency, the expected catch on the second day of spraying would only average 69 per cent. of the catch on the first day. Therefore in the results, as enumerated in Table IV, the second day's catch has in each case been expressed as a percentage of the expected catch, which was calculated on this basis. That this method fully compensates for the declining population is demonstrated by the second day catch of male *A. minimus*, which was actually greater than expectation, and indicated that the morning spraying had no deterrent effect on their entry during the following nights. The low second day catches of gravid females are explainable on the hypothesis that most gravid females in huts had remained there for two successive nights. The low percentage of expectation of fed females, however, must be the consequence of a repellent effect; this result is based on large numbers of mosquitos and is consistent from day to day. Whereas the repellent effects caused by pyrethrum affected males most strongly, the Lethane-kerosene repellency to *A. minimus* had a much stronger effect on females.

These experiments had been preceded by a series of night catches in the same huts, on 12 occasions during the previous month. This work involved spraying each hut at 9 a.m., and then spraying it at either 9 p.m., 11 p.m. or 1 a.m. on the following night, and again at 8 a.m. on the second morning. The results concerning unfed and fed female *A. minimus* will be interpreted elsewhere, but the results concerning gravid and male *A. minimus*, and both sexes of *A. vagus*, can be given here, and are scheduled in Table V. In all these cases entry occurred in the early morning, and only stragglers entered before 1 a.m. The numbers of such stragglers are given in brackets in the table, and they are included in the totals and percentages in order not to invalidate them. The results show, as would be expected, a progressive increase in repellency as the interval between spraying and entry time diminished. They indicate that entry of female *A. vagus* was not diminished by spraying at 9 p.m., but was reduced progressively by spraying at 11 p.m. or 1 a.m. The numbers of male *A. vagus* were small, and perusal of the daily records has shown great fluctuation in their entry numbers, thereby producing the inconsistent result that the 9 p.m. spraying seemed more repellent than later ones. The results do indicate, however, that male *A. minimus* were affected less than male *A. vagus*, and this conclusion is also in contrast to the results for pyrethrum repellency effects.

Demonstration of Repellency of Pyrethrum by Night Catches.

When the marked reductions in mosquito infestation, as measured by daytime catches, had been recorded, it was important to determine whether these reductions were caused by reduction in mosquito entry, or by abnormal egress.

Two pairs of huts were selected, all in the same part of the coolie line, and all having been collected from regularly during previous weeks. One pair was then sprayed with 0·1 per cent. pyrethrum in kerosene, as usual, in the afternoon, while the second pair was left unsprayed. At 11 p.m. all four huts were resprayed, and their mosquitos collected.

In Table VI the results of the night catches, both with and without previous afternoon spraying, can be compared. In compiling this table male and half-gravid female *A. minimus* were ignored, and only numbers of unfed, partly fed and fully

TABLE V.

Short Period Repellency of Lethane-Kerosene.

Totals from 12 experiments: 1.ix—2.x.45.

	9 p.m.–dawn.			11 p.m.–dawn.			1 a.m.–dawn.		
	Catch morning before 9 p.m. spraying.	Catch morning after 9 p.m. spraying.	Per-centage.	Catch morning before 11 p.m. spraying.	Catch morning after 11 p.m. spraying.	Per-centage.	Catch morning before 1 a.m. spraying.	Catch morning after 1 a.m. spraying.	Per-centage.
Gravid *A. minimus*	181	16	9%	292	22	7·5%	203	14(4)	7%
Male *A. minimus*	120	51(4)	39%	143	114(1)	79%	95	41(1)	42%
				Average 61%					
Female *A. vagus*	91	92	101%	156	93	60%	192	76(3)	40%
Male *A. vagus*	18	9	50%	19	10	53%	26	5	19%

TABLE VI.

Numbers of Non-Gravid Female *A. minimus* obtained before and during Night Spraying.

	Afternoon catches from both pairs.					Totals.	Afternoon.	11 p.m.	Afternoon.	11 p.m.
Date.	21.x.	25.ix.	3.x.	7.x.	11.x.		19.x.		23.x.	
First pair	22	57	42	9	123	253	Not sprayed	19	9	0
Second pair	31	52	24	7	115	229	46	3	Not sprayed	6
Ratio, first to second pairs	0·71	1·10	1·75	1·29	1·07	1·11		6·34		0
Expected night catch in previously sprayed huts, based on 1·11 ratio								17·1		6·65
Actual night catch in previously sprayed huts, as percentage of expected night catch								12·6%		

fed females included. A rapid decline in the numbers of the mosquito population terminated this experiment prematurely, but the two results obtained are sufficient to demonstrate that there was a reduction in the night population of *A. minimus* in the sprayed huts which was of a similar extent to the reductions previously found among the resting day populations therein, and it may be inferred, therefore, that the repellency effects demonstrated in the pyrethrum experiments are the consequence of reduction in mosquito entry. Since two-thirds of the female *A. minimus* found in 11 p.m. catches were unfed and females usually rest in huts for some time before feeding, it was not possible to explain these results on the supposition of abnormal egress of fed females.

Conclusions.

Interpretation of Results.

No statistical estimate can be made of the probable margin of error entailed in these results, but their consistency provides the best justification for the techniques involved both in sampling and assessing the results. As examples of this consistency may be mentioned (i) the close parallels between the results with pyrethrum in kerosene and those of the pyrethrum aerosol; (ii) the agreement between the results concerning female and male *A. vagus*, as given in Tables III and V, and (iii) the results for fed *A. minimus* as scheduled in Tables III and IV.

The close similarity between the pyrethrum-kerosene and the pyrethrum aerosol indicates that pyrethrum is the repellent agent in both of these cases and I consider that the lack of persistence of the repellency produced by the Lethane 384-kerosene spray indicates that most of this repellency is produced by the quickly-evaporating Lethane. These conclusions conflict with those of Senior White & others (1945), who thought that the repellent effects of pyrethrum-in-kerosene sprays appeared to be more the result of the kerosene oil than of the pyrethrum.

Types of Repellency.

The night catches have indicated that the effects of pyrethrum were vapour effects, which deterred mosquito entry, and not the consequence of irritation and egress after contact with sprayed surfaces. Those of Lethane in kerosene were almost certainly similar.

I think that the effects can be divided into two separate categories. Repellent effects proper were exemplified in the pyrethrum results, and a characteristic of them was that males were slightly more sensitive than females of the same species; this condition was found to obtain among all species. The male sensory organs are probably capable of greater discrimination. The short period repellent effects of Lethane-kerosene on *A. vagus* observed the same criterion, and should be attributed to repellency.

The effects of Lethane-kerosene on *A. minimus* after morning spraying (Table IV) did not answer this criterion. Instead there was a 47 per cent. reduction in non-gravid females, but no reduction in males. I consider that this is not a repellent but a masking effect, resulting from the attracting scent of the human inhabitants being observed by the odour of the Lethane and/or kerosene. Another masking effect has been demonstrated to occur among West African Anophelines (Ribbands, 1946b), through the scent arising from a large area of cut and withering bush, and in that instance the population of entrant females of both *A. gambiae*, Giles, and *A. funestus*, Giles, declined in greater measure, to 25–33 per cent. of expectation, while the proportion of entrant males declined only to 50 per cent. I think it is likely that whereas blood-seeking females are attracted by scent, shelter-seeking Anophelines are attracted by light or temperature gradients. On this supposition, females only would be sensitive to the masking effect, as in the Lethane results now presented.

It is likely, of course, that repellent and masking effects combine in various degrees in different circumstances and with different species, and probable that the West African bush clearing experiment showed a predominant masking effect, with a subsidiary repellent effect (demonstrated by the lesser decline in the proportion of males).

Species Differences in repellent Sensitivity.

While it is obvious that the masking effect will be far greater among anthropophilic species, the results show that species also vary in their sensitivity to the repellent effect. Thus *A. minimus* were considerably more sensitive to pyrethrum than either *A. vagus* or Culicines, and this result was applicable to both sexes, and with the pyrethrum in either form. In addition, the relative sensitivity of the species varies with the repellent, because male *A. minimus* were less sensitive than male *A. vagus* to Lethane/kerosene.

The very marked sensitiveness to pyrethrum which is shown by *A. minimus* may not be characteristic of all anthropophilic Anophelines. While in West Africa in 1940–43, I consistently used spray catching methods against *A. gambiae* and *A. melas*, Theo., but I did not encounter such marked effects, and was able to make daily catches by spray catching in the same huts every morning for nearly one year (Ribbands, 1944). Application of the same methods to *A. minimus* in Assam was quickly found to be impossible, and that fact engendered the present study. West African conditions differed from those in Assam in two other respects, as well as in the difference between the mosquito species. In the first place, specially built huts were used, with abundant ventilation all day; this probably reduced the repellent effect, although experiments in Assam showed that *A. minimus* exhibited marked repellency under such circumstances. Secondly the African experiments were conducted in isolated huts which were a long distance away from any untreated huts; it is possible that when the mosquito is offered a choice of sprayed or unsprayed huts it is more fastidious than when only sprayed huts are readily available.

Anti-Malarial Applications of these Results.

These results show that the risk of malaria transmission by *A. minimus* can be considerably reduced by thorough spraying of living quarters every evening. Assessment of the value of such a measure against other malaria carriers is rendered speculative by the variation in repellent sensitivity which occurs between different species, but it is likely that it would nearly always be of some value.

Insecticides for research Purposes.

The superiority of Lethane 384 over pyrethrum for insecticidal use in experiments which involve repeated catchings has been clearly demonstrated. As an insecticide, Lethane was found to be quite satisfactory in the heavy dosage used, and to give a quicker knockdown than pyrethrum. Discovery of an efficient insecticide possessing no residual repellent or masking effect would be a considerable contribution to modern technique, and would materially facilitate quantitative studies involving mosquito populations.

For survey purposes where the repellent effect is of no consequence, pyrethrum is very preferable to Lethane, because the latter is so unpleasant. Pyrethrum aerosol provides specimens in better condition than pyrethrum flitting, but as the globules are smaller the rate of knockdown is often slower, and the chance of escape from the room before death is increased.

Summary.

(1) Spraying of huts with 0·1 per cent. pyrethrum in kerosene, at the rate of 25 c.c. per 1,000 cubic feet, deterred 90 per cent. of *A. minimus* from entry on the following night. The repellent effect persisted in diminished degree for at least four days.

(2) A rather larger quantity of pyrethrum, sprayed in a Freon aerosol, produced a similar but somewhat less marked effect.

(3) The repellent effects of Lethane 384 in kerosene were much less marked, and not discernible on the second night.

(4) Different species varied greatly in their sensitivity to the repellents.

(5) Two types of repellent effects were indicated. Repellent effects proper were the most important, and males were more sensitive to these than females of the same species. There was also a masking effect, to which anthropophilic females were sensitive, which resulted from obscuring of attractive human scents by the chemical odours.

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THE USE OF ADHESIVE AGENTS IN DDT SPRAYS.

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Introduction.

A previous investigation on the residual toxicity of DDT[1] when applied to the surface of different building materials (Barnes, 1945) showed that the toxicity of a smooth surface treated with DDT diminished considerably after repeated rubbing or washing. The primary object of the present work was, therefore, to establish whether or not DDT when applied with certain adhesive agents to a smooth surface would better withstand such simple household operations. At the same time, tests were carried out to ascertain to what extent the presence of adhesive agents would (i) improve the persistent toxicity of a DDT-treated surface, and (ii) reduce absorption of DDT by a porous surface.

The bed-bug (*Cimex lectularius*, L.) because it is widely distributed and infests surfaces, both exposed and hidden, was chosen as the test insect.

Material and Technique.

Bugs used throughout this work were obtained from a laboratory culture (originally collected from the London area), kept at 25° C. and fed weekly on rabbit blood. Adult bugs only were used and were standardised in respect of age and nutrition.

The sample of DDT used was the pure para para compound, free of isomers, with melting point 109° C.

Blocks of the materials to be treated, measuring approximately 2 in. by 2½ in., were sprayed in a tower, devised by Potter (1941), with different volumes of a solution of DDT and an adhesive agent in a mixture of nine parts of odourless distillate[2] and one of ethylene dichloride, to give varying deposits of solutes per square centimetre of surface. (1 c.c. of this mixture sprayed in a Potter tower gave a deposit of approximately 0·36 mg. per sq. cm.) Forty-eight hours later, when the blocks had dried at room temperature, bugs were exposed on the sprayed surface for 24 hours; they were then transferred to clean recovery tubes and kept at 25° C. for a period of six days, at the end of which mortality counts were made. During the intervals between subsequent tests, the blocks were hung on a wall of the laboratory and left undisturbed at ordinary room temperature, in diffuse daylight, not protected from dust.

The residual Toxicity of Materials treated with DDT and adhesive Agents.

The following materials were selected for testing :—

(i) Keen's cement, as an example of a porous material ;

(ii) Baltic red-wood, as an example of a smooth surface.

Blocks of this wood were sawn across the grain and had been coated three years previously with an oil-type paint.

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[1] The synthetic insecticide dichlor-diphenyl trichlorethane.

[2] A refined light oil, slightly above paraffin cut. S.G., ·779 ; B.P., 200° C. ; flash point (closed), 71° C. ; viscosity, Redwood I, 32 sec. at 20° C.

Blocks of these materials were sprayed with varying quantities of a solution containing 4 per cent. (wt./vol.) of DDT and an equivalent weight of one of the following adhesive agents :—

(i) coumarone resin[1] ;

(ii) a mixture in equal parts of paraffin wax (52° C. M.P.) and commercial vaseline.

(iii) boiled linseed oil.

The insecticidal power of the blocks was tested 48 hours, one, two and three months after treatment. Six blocks of each material were used for a single test and eight bugs were exposed on each block at the specified intervals ; each result is therefore based on 48 bugs.

Table I summarises the percentage mortalities of bugs given at these intervals by the materials after they had been treated with varying deposits of DDT and adhesive agent per square centimetre of surface[2].

TABLE I

Percentage mortality of bugs given at intervals by materials treated with DDT and an adhesive agent. (In this and the following table each percentage mortality was based on deaths obtained among 48 bugs.)

Deposit of— (a) DDT. (b) adhesive agent (mg/cm²).	Tested at intervals of :	Coumarone resin.		Paraffin wax/ vaseline.		Boiled linseed oil.	
		Keen's cement.	Painted wood.	Keen's cement.	Painted wood.	Keen's cement.	Painted wood.
(a) 0·005 .. (b) 0·005 ..	48 hours	60	77	58	25	64	27
	1 month	62	23	56	8	50	14
	2 months	21	18	30	5	27	5
	3 months	8	8	20	8	7	8
(a) 0·01 .. .. (b) 0·01	48 hours	70	95	70	50	81	50
	1 month	73	25	75	27	60	17
	2 months	53	20	52	19	33	5
	3 months	33	25	35	8	22	9
(a) 0·03 .. .. (b) 0·03 ..	48 hours	92	97	90	87	83	98
	1 month	70	25	90	37	73	47
	2 months	72	22	88	42	75	25
	3 months	52	23	64	19	66	20
(a) 0·06 .. .. (b) 0·06	48 hours	93	97	100	92	89	100
	1 month	81	83	97	98	75	94
	2 months	70	61	96	90	80	75
	3 months	72	62	92	70	83	60

The salient points that emerge from this table are :—

(1) Forty-eight hours after treatment with the lower doses employed, painted wood was more toxic when sprayed with DDT and coumarone resin than with DDT and either paraffin wax and vaseline or boiled linseed oil ; at the heavier deposits, the toxicity of the DDT-treated surfaces was high, irrespective of the adhesive agent used.

[1] The sample of coumarone resin used was supplied by the Geigy Pharmaceutical Co., Ltd., and contained 50 per cent. by weight of DDT.

[2] 1 mg. of DDT (or adhesive agent) per square centimetre is approximately equivalent to 930 mgs. per sq. foot.

(2) The residual toxicity of painted wood treated with the lower doses of DDT and any one adhesive agent diminished considerably within one month of spraying; only at the maximum dosage employed, namely 0·06 mg. per sq. cm. of both DDT and adhesive agent, did the toxicity of the treated surface persist for at least three months.

(3) The residual toxicity of cement, tested at any one specified interval after treatment with a given deposit of DDT, was approximately equal in the presence of each of the adhesive agents used.

(4) Unlike that of painted wood, the residual toxicity of cement, treated with a given deposit of DDT and any one adhesive agent, diminished gradually over a period of three months.

The Effects of Washing and Rubbing similarly treated smooth Surfaces.

Panels of painted wood and glass, treated with a deposit of 0·03 mg. per sq. cm. of both DDT and one of each adhesive agent, were either dusted or washed with tepid water and soap once weekly for at least three weeks, and their toxicity to bed-bugs tested after each washing or dusting. In both operations the surface of the panels was rubbed six times from side to side with as evenly distributed a pressure as possible. Six rubbings were sufficient to remove from the surface all visible traces of DDT crystals and, in the case of glass, the opaque film which was deposited after spraying. For purposes of comparison, the toxicity of the sprayed surfaces was tested before the first washing or dusting.

In order to ascertain the effect of increasing the dose of adhesive agent alone, similar tests were carried out on a further series of glass and painted wooden blocks sprayed to give deposits of 0·03 and 0·06 mg. per sq. cm. respectively of DDT and boiled linseed oil.[1] Table II embodies the percentage mortality given by both series of glass and painted wood tested 48 hours after spraying and after each washing or dusting.

Table II

Percentage mortality of bugs on smooth surfaces treated with DDT and adhesive agent and washed and rubbed frequently.

Adhesive agent.	Before washing, etc.	After washing.				After dusting.			
		1st	2nd	3rd	4th	1st	2nd	3rd	4th
Coumarone resin—									
*Old painted wood	95	75	46	16		96	80	33	
*Glass	100	65	50	33					
Paraffin wax and vaseline—									
*Old painted wood	90	55	20	25		90	40	28	
*Glass	100	75	40	17					
Boiled linseed oil—									
*Old painted wood	96	66	37	0		95	40	6	
*Glass	100	75	50	28					
†Old painted wood	94	62	33	35	29	90	76	25	19
†Glass	100	79	44	28					

*Having deposits of 0·03 mg. DDT and 0·03 mg. adhesive agent per sq. cm.
† Having deposits of 0·03 mg. DDT and 0·06 mg. adhesive agent per sq. cm.

It is seen that the presence of an adhesive agent, whether in light or heavy doses does not prevent the removal, by repeated washing or dusting, of DDT from a treated surface. Moreover, an increase in the dose of adhesive agent does not result in a marked increase in the toxicity of the sprayed surface.

[1] It was not possible to spray in a Potter tower a solution of paraffin wax and vaseline of sufficient concentration to give a deposit of 0·06 mg. per sq. cm. The sample of coumarone resin used was supplied with DDT already combined in it (50 per cent. by weight). For these reasons, the tests were confined to DDT and boiled linseed oil only.

Summary and Discussion.

A previous investigation by the writer established that the minimum deposit of DDT on both cement and old painted wood necessary to ensure complete mortality of bed-bugs 48 hours after spraying was 0·2 mg. per sq. cm., and that the toxicity of both surfaces diminished slowly over a period of six months. The present work has shown that when DDT is applied with an adhesive agent, the minimum deposit of insecticide necessary on these surfaces to yield a similar kill at the same interval after treatment was only 0·06 mg. per sq. cm. The addition of an adhesive agent to a DDT spray thus effects considerable economy in the use of DDT. Campbell and West (1944), investigating the toxicity to houseflies of coumarine resin and DDT dissolved in white spirit, have reported an increase in the efficiency of DDT when sprayed with an adhesive agent. These authors confined their investigation to a resin only and they suggested that the coumarone resin conferred, in a manner not specified, increased insecticidal activity on the DDT. The present work has shown that relatively small doses of DDT are highly effective in the presence of at least three dissimilar adhesive agents. It is possible, therefore, that instead of increasing the activity of DDT, the agent merely blocks the minute pores of the treated surface, and by minimising absorption of the solution, increases the amount of DDT available to the insect. Alternatively, the adhesive agent may have some affinity for substances on the surface of the bug's tarsi and so assist transfer of DDT from the sprayed surface to the insect.

The residual toxicity of cement treated with DDT and an adhesive agent, like that of a similar surface treated with DDT alone, diminished slowly. The toxicity of painted wood, on the other hand, treated with doses of DDT and adhesive agent ranging from 0·005 to 0·02 mg. per sq. cm., decreased within one month, irrespective of the adhesive agent used. This fall in toxicity is puzzling, particularly in view of the fact that no such decrease occurred when the surface was treated with a heavier deposit of DDT and adhesive agent, namely 0·06 mg. of each per sq. cm. This latter observation seems to preclude a possible interference with the efficiency of DDT by a slow interaction of the paint constituents and the adhesive agent.

The application of these adhesive agents, even in relatively high doses, failed to prevent the removal of DDT from a smooth surface by repeated washing and rubbing; furthermore, an increase in the deposit of adhesive agent does not markedly increase the insecticidal efficiency of a given deposit of DDT.

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FACTORS INFLUENCING THE INTERACTION OF INSECTICIDAL MISTS ON FLYING INSECTS.

Part III. Biological Factors.

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CONTENTS

Introduction.

The interaction between insecticidal mists and flying insects has already been discussed in a previous paper in which particular attention was given to the behaviour and properties of the spray mist and the effect that variations in these had upon the biological efficiency of the spray (David, 1946b). It is also possible to investigate the relationship between the insect and the spray mist from the standpoint of the insect. The present paper therefore considers the influence that certain variations in the behaviour and physiological state of the insects have on either the quantity of spray accumulated or the response produced.

Methods.

The apparatus employed in carrying out the tests concerned has already been described (David 1946a). Essentially it consisted of a constant temperature cabinet, volume 54·5 cu. ft. (=1543 lit.) which was maintained at 28°C. and brought to 70 per cent. relative humidity before each test. The atomiser was an Aerograph M.P. type paint spray gun fitted with a No. 1 conical nozzle. It was operated at 12·5 lbs. per sq. in. and usually 0·7 c.c. of spray solution were employed. The test insects, *Aëdes aegypti*, bred according to the method already described (David,

Bracey & Harvey, 1944) were introduced into the spray chamber in cages four minutes after the time of commencement of spraying and were exposed for ten minutes. The procedure just described will in future be referred to as the standard testing conditions.

Assessment of Results.

Except where otherwise stated, batches of insects containing individuals ranging from one to four days old were employed in the tests, and the numbers used on each occasion are indicated below the tables. Eighteen to 24 hours after the exposure the percentage kills of males and females were determined and either reported separately or averaged. Any insects capable of even the slightest movements were counted as alive. In certain cases the results were converted to angles (Bliss, 1938) and an analysis of variance was carried out.

Behaviour as a Factor influencing the Response of *Aëdes aegypti* to Insecticides.

It has already been suggested that the collisions between a spray droplet and an insect may be occasioned primarily either by the movements of the droplets or by those of the insects although in certain circumstances both act concurrently (David, 1946b). Under the conditions that prevailed in the spray chamber when following the standard testing procedure, the collisions were brought about almost exclusively by the movements of the insects as was demonstrated by the series of experiments discussed below. In fact it is of course obvious that an insect which flies through a very fine mist dispersion, in which the particles are only settling very slowly, must accumulate more spray if its movements are rapid, compared with those of the droplets, than insects which remain stationary.

1. *The influence of flight on the dose accumulated.*

Four batches of insects were separated from a culture of *Aëdes* and treated as follows :—

(*a*) Untreated controls.

(*b*) Chloroformed and allowed to recover fully.

(*c*) Chloroformed, wings amputated and then allowed to recover.

(*d*) Chloroformed and exposed before recovery took place.

If, as suggested above, the insects accumulated the spray droplets in appreciable numbers from fine mist dispersals (particles below 10 microns diameter) only when they fly through the mist it would be expected that insects in groups (*a*) and (*b*) would be much more affected by the spray than the walking or motionless insects in groups (*c*) and (*d*) respectively. The results in Table I show that this was so. The test was carried out according to the standard procedure, the insects being introduced into the spray chamber in cages four minutes after spraying (*see also* David & Bracey, 1944).

TABLE I.

State of the insects.	Average % kill in 24 hours.	Average angle ± 1·2°.
Control (*a*)	62	51·7
Chloroformed and recovered (*b*)	58	49·3
Wingless (*c*)	15	22·7
Under chloroform (*d*)	12	20·3

The effect of a pyrethrum spray (0·1% w/v) on flying (*a*) and (*b*), walking (*c*) and motionless (*d*) insects exposed simultaneously. Each result represents the average of three determinations on 50 insects.

2. *The speed of flight and the dose accumulated.*

While it would probably be impossible to control the speed of flight of a group of mosquitos exposed to an insecticidal mist, it can be readily shown that by moving the mist charged atmosphere past motionless insects at different velocities the quantity of insecticide impacting, as shown by the percentage kill obtained, increases progressively with the wind speed.

The procedure employed was as follows. Chloroformed mosquitos were placed on a piece of mosquito netting held in a thistle-funnel attached to the neck of a Buchner filter flask. The flask was placed in the spray chamber and a known volume of the spray treated atmosphere was drawn through the funnel at known wind speeds. The apparatus is shown in fig. 1. The wind speeds were controlled by a series of capillary resistances inserted in the suction line and calculated for the gauze area on which the mosquitos were resting.

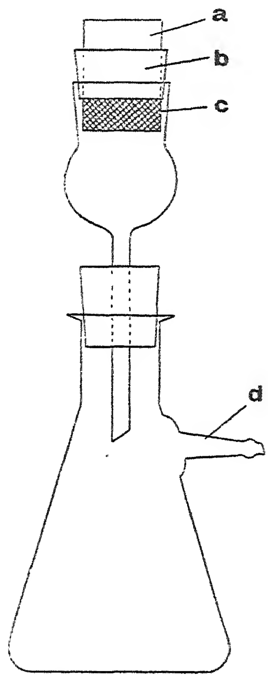

FIG. 1.—Insect impactor : *a*, glass cylinder surrounded by rubber ring *b*, and covered at the bottom with mosquito netting *c*, held between *a* and *b*. The mist enters through *a* and is drawn off through *d*.

From the results set out in Table II, it can be seen that as the wind speed increases so the percentage kill obtained also increases. Therefore, although the orientation of the chloroformed mosquitos on the mosquito netting to the airstream will be very different from that of insects in flight through a mist, it seems safe to conclude that the quantity of insecticide impacting on an insect will also increase as the speed of flight increases. This result would be in accordance with fundamental physical principles.

TABLE II.

Wind speed, m.p.h.	Average % kill in 24 hours.	Average angle ± 2·2.
0·5	10	17·5
0·8	16	23·5
1·5	34	35·5
2·4	56	48·0
3·0	78	61·5

The relationship between the rate of movement of the mist charged atmosphere and the percentage kill of motionless *Aëdes aegypti* exposed to it. Each result represents the average of two determinations employing about 100 insects for each test. The spray solution was 0·1% w/v pyrethrins and 0·7 c.c. was injected into the chamber.

3. *The effect of mechanically induced variations in flight activity on the quantity of insecticide accumulated.*

It was observed that certain batches of *Aëdes* naturally flew much more actively than others and that the level of activity was apparently uninfluenced by exposure to kerosene sprays containing 0·5 per cent. wt./vol. of 2,2-bis (parachlorphenyl) 1,1,1-trichlorethane (henceforward referred to as DDT). When inactive insects were exposed to the spray only, a very low kill resulted, but by tapping the exposure cage the insects were stimulated into flight and a much higher kill was then obtained. The possible response of naturally active insects when they were treated in this way was of course much less and the increment in the percentage kill produced by tapping the cage in which they were being exposed was correspondingly smaller. The results obtained in two experiments of this kind are shown in Table III and they provide further confirmation of the fact that the heaviest dose of insecticide is accumulated by the most actively flying insects.

TABLE III.

Treatment of exposure cage.	Naturally inactive insects.		Naturally active insects.	
	Average % kill in 24 hours.	Average angle ± 1·2.	Average % kill in 24 hours.	Average angle ± 3·0.
Not tapped.. ..	14	22	72	58
Tapped	63	53	88	70

The effect of mechanically disturbing insects exposed to a DDT spray on the percentage kill recorded. Each result represents the average of two determinations on about 100 insects.

4. *The effect of chemically induced variations in flight activity on the quantity of insecticide accumulated.*

In the previous experiment the activity of a test group of insects was increased by vibrating the exposure cage. In the present case the activity was increased by adding 0·02 per cent. w/v of pyrethrins to the DDT spray used in the test. Besides

pyrethrins other materials which it had been suggested might be effective irritants were also tested, notably "Lethane 384 Standard" (a proprietary preparation of beta butoxy beta′ thiocyanodiethyl ether) and cyclohexanone. Only pyrethrins proved to be effective, however, as can be seen by reference to Table IV. At the time at which the tests were carried out the insects, which were between one and two days old, showed a low level of natural flight activity. It should be added that at the concentration used the pyrethrins caused little knockdown.

TABLE IV.

Composition of spray.	% Knocked down after 2 minutes.	4	6	8	10	Average % kill in 24 hours.	Average angle ± 1·5.
DDT 0·5% w/v	0	0	0	0	0	14	21·7
DDT 0·5% w/v Cyclohexanone 5·0% v/v	0	0	0	0	0	13	21·0
DDT 0·5% w/v Lethane 5·0% v/v	0	0	0	<10	10	14	21·7
DDT 0·5% w/v Pyrethrins 0·02% w/v	0	0	0	0	10	60	51·0

The effect on the observed kill of increasing the activity of insects exposed to a DDT spray by incorporating a small percentage of pyrethrins. The average figures are based on three determinations on about 100 insects.

The results of these four experiments all point to the same conclusion, namely that insects which fly through a finely dispersed spray mist (*i.e.* particle size under about 10 microns diameter) accumulate many more spray droplets than those insects which remain motionless in the mist. Furthermore, it may be suggested that insecticides which do not excite insects into active flight are unlikely to be effective by mist action against species such as mosquitos which frequent sheltered resting places. DDT is a case in point of an insecticide which does not exert a strong irritating effect on mosquitos in minimal amounts and its effectiveness and reliability is greatly increased when used in conjunction with pyrethrins which have an exceptionally strong irritating action on mosquitos. When the movement of the spray droplets are responsible for the effective collisions the above conclusions regarding the advantages of adding pyrethrins to DDT sprays would, of course, not hold good.

Biological Factors influencing the Resistance of *Aëdes aegypti* to Insecticides.

It is already well known that the individuals within a given batch of insects show a more or less normal distribution of resistance to insecticides, that the mean resistance tends to vary from culture to culture and that the level of resistance changes with the age of the insects and various other factors. Fluctuations in the level of resistance with age have been reported in the case of house-flies (Grady 1928, Simanton and Miller 1937) and cockroaches (Tuma 1938) while the two sexes also show consistent differences in susceptibility, for example, in the case of house-flies (Murray 1937, 1938) and *Drosophila* (Lord 1942). The susceptibility to poisons is also known to be influenced by the nutrition of the larva and the adult in the case of house-flies bred for the Peet-Grady test (Murray 1937).

In the preceding section it was shown that the quantity of insecticide accumulated during exposure to a spray mist increased with the activity of the insects. This fact should be borne in mind when considering any differences in susceptibility which appear to exist between either the two sexes or between batches of insects

of various ages since the variations observed may be merely expressions of differences in the average level of activity. Whether this is so or not could only be satisfactorily resolved by measuring the amount of insecticide actually accumulated by the exposed groups. Meanwhile the activity factor has been disregarded except in certain experiments where the insecticide was applied by the impaction method.

1. *The relative resistance of male and female* Aëdes aegypti *to insecticides.*

It has already been explained in the introduction that the culture of *Aëdes* normally employed contained individuals ranging in age from one to four days. Since the males tend to emerge first they are on the average older than the females (Buxton & Hopkins 1927) and they should be more susceptible to poisons on this account since, as will be shown later, the susceptibility of both sexes increases with age.

(*a*) Preliminary observations:

The majority of the results given in this section were accumulated in the course of a programme of routine work on the formulation of insecticidal sprays using the standard testing procedure which has already been described (*see* David 1946b and introduction to the present paper). Information was obtained regarding pyrethrum, DDT and mixed DDT-pyrethrum sprays and typical selections from the results obtained are given in figs. 2a, b and c.

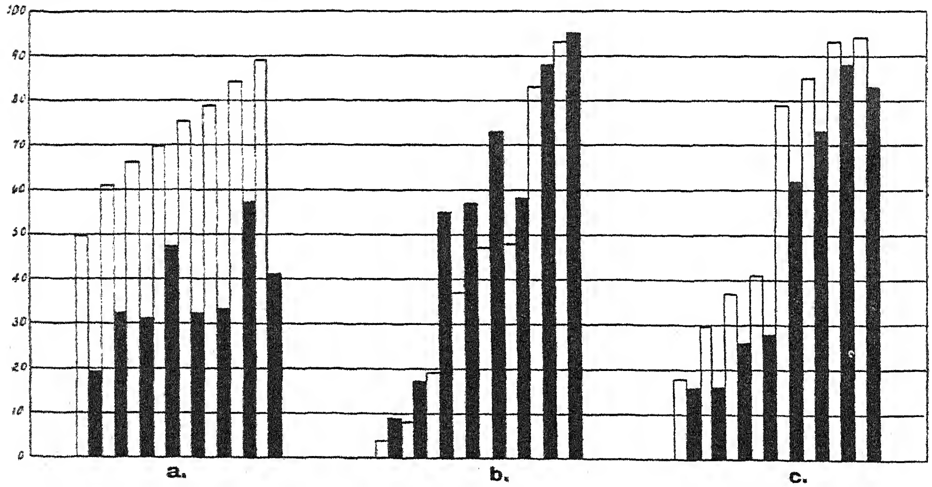

FIG. 2.—The relative resistance of male and female *Aëdes aegypti* 1–4 days old to (*a*) pyrethrins 0·10% w/v; (*b*) DDT 0·5% w/v; (*c*) DDT 0·5% w/v + pyrethrins 0·01% w/v, all in odourless kerosene. In each case data from eight cultures are presented. The percentage kills of males are shown by the white columns and the black columns immediately to the right show the kills of females on the same cultures.

In 19 experiments in which the OTI (0·1 per cent. w/v pyrethrins) was sprayed average kills of 64 per cent. males and 38 per cent. females were obtained, the individual percentage kills of males being invariably higher than those of females. In contrast with the foregoing, in eight experiments in which an 0·5 per cent. w/v solution of DDT was sprayed a final average of 42 per cent. males and 55 per cent. females killed were obtained, the individual values for males being invariably lower than those for the females in the same batch. Since it had been observed that *Aëdes* were rather inactive when exposed to DDT spray mists 0·01 per cent. w/v of pyrethrins was added to the 0·5 per cent. w/v DDT spray. The average kills of males and females with this spray (in which the lethal action must be attributed almost exclusively to the DDT present) were now 59 per cent. and 48 per cent. respectively in eight tests, the males being consistently more susceptible than the females (fig. 2c).

It will be noted that, in the presence of pyrethrins, male *Aëdes* show a higher percentage kill than females exposed simultaneously irrespective of whether the lethal action is to be attributed to pyrethrins or DDT. In pure DDT sprays on the other hand, slightly lower kills of males than females were invariably obtained. This apparent reversal of the order of resistance of the sexes in DDT as compared with pyrethrum sprays is probably attributable to the fact that in DDT sprays the females fly more, relative to the males, than they do in pyrethrum sprays. Confirmation of this suggestion was obtained by impacting pyrethrum and DDT sprays on motionless insects. When the activity factor was eliminated both sprays showed a greater kill of males than females (Table V).

TABLE V.

Culture No.	Average percentage kill after 24 hours.			
	Pyrethrins 0·05% wt/vol.		DDT 0·3% wt/vol.	
	Male.	Female.	Male.	Female.
1	70	33	85	54
2	69	22	72	49
3	82	37	82	49
4	79	36	80	62
5	86	31	83	75
Average % kill	77	34	80	58

The relative resistance of male and female *Aëdes aegypti* to pyrethrins and DDT by the impaction method. About 100–200 insects were employed in each test.

(*b*) The relative resistance of male and female *Aëdes* to pyrethrins:

In addition to the preliminary experiments just reported a more detailed investigation of the relative resistance of male and female *Aëdes* to pyrethrins was carried out. A culture of insects varying between one and four days old was sprayed with pyrethrins at four different concentrations following the standard testing procedure. The results obtained are presented in Table VI and graphically in fig. 3. It can be seen clearly that over the whole of the mortality range the males are more susceptible than the females.

TABLE VI.

Concentration of pyrethrins in spray, % wt/vol.	Average % kill after 24 hours.		Average angle ± 1·2.	
	Male.	Female.	Male.	Female.
0·03	14	7	22	15
0·07	87	30	69	33
0·10	95	56	77	48
0·13	98	71	82	57

The relative resistance of male and female *Aëdes aegypti* to pyrethrins at various concentrations applied according to the standard testing procedure. The average figures are based on four determinations each involving 50–100 insects.

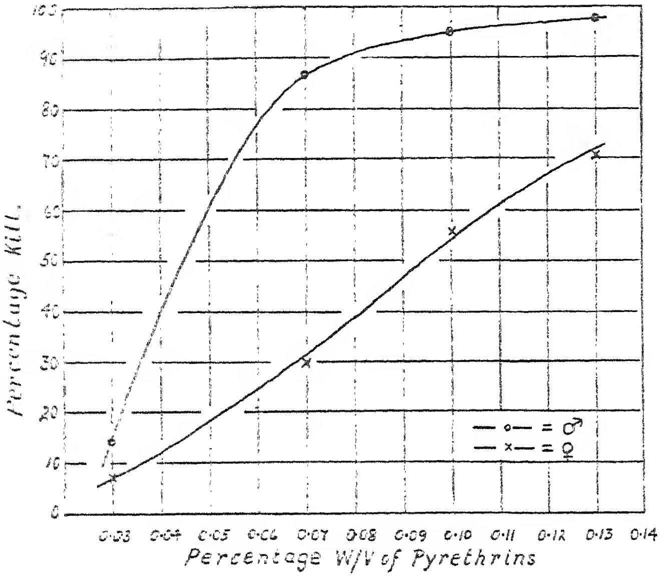

FIG. 3.—The relative resistance of male and female *Aëdes aegypti* 1–4 days old to various concentrations of pyrethrins in odourless kerosene.

2. *The change of resistance of male and female* Aëdes aegypti *with age.*

It has previously been shown that the resistance of insects to poisons varies with the age of the culture and commonly reaches a maximum when the insects are a few days old (Simanton & Miller 1937, Tuma 1938). In the tests previously described the cultures contained individuals varying in age between one and four days but for the purpose of certain tests in this section the age range was reduced to one or two days. By limiting eclosion to these shorter periods the age range within the culture was restricted and the early emerging males and the late emerging females were excluded so that the average age of the two sexes was much more equal. It is interesting to note that as a result of this procedure the difference between the resistance of the sexes in the youngest age group appeared to be largely eliminated but was re-established as the group aged (Table VIII).

(*a*) The change of resistance with age to a pyrethrum spray:

Several experiments which were carried out to follow the change of resistance with age all gave essentially the same results. There was always a progressive decrease in resistance with age from the youngest test groups although the rate of decline of resistance showed variations in different cultures. The reasons for this variability are discussed later.

Two examples of the change of resistance of cultures of *Aëdes* in which the individuals were collected over a period of 48 hours, maintained at 28° C. and 70 per cent. relative humidity and fed on water and sugar are presented in Table VII.

TABLE VII.

Age in days.	Average percentage kill in 24 hours.					
	Example 1.			Example 2.		
	Male.	Female.	Average.	Male.	Female.	Average.
0–2	36	16	26	37	10	24
1–3	59	27	43	62	17	40
2–4	73	34	54	—	—	—
3–5	—	—	—	95	50	73
4–6	80	56	66	—	—	—
5–7	—	—	—	—	—	—
6–8	—	—	—	100	68	84

The change of resistance of cultures of *Aëdes* between 0 and 2 days old to 0·10 and 0·08 % wt/vol. solutions of pyrethrins respectively. Each average figure is based on four determinations each of which involved about 100 insects.

Except for negligible difference in resistance between the males and females in the youngest test group, which was also found in *Musca* (Miller & Simanton 1938) an experiment was carried out on a test group in which the eclosion period was restricted to 24 hours gave essentially the same result.

TABLE VIII.

Age in days.	Average percentage kill in 24 hours.		
	Male.	Female.	Average.
0–1	37	34	36
3–4	65	49	57
4–5	81	53	67

The change in resistance of *Aëdes* up to one day old to pyrethrins. Each average figure is based on two determinations involving 50–100 insects each.

Since it seemed possible that an activity factor which affected the dose accumulated in the way already discussed was partly responsible for this rapid decline of resistance with age, a test was made following the impaction procedure. The results obtained were essentially similar to those previously described and it must be concluded that a real decline in resistance has taken place and that the change is not attributable to a progressive increase in the dose accumulated (Table IX). In contrast with *Musca* (Simanton & Miller 1937) and cockroaches (Tuma 1938) the resistance of *Aëdes* to insecticides decreases from the first and does not reach a maximum figure when the insects are a few days old.

TABLE IX.

Age in days.	Average percentage kill in 24 hours.		
	Male.	Female.	Average.
0–2	15	5	10
2–3	40	18	29
3–4	81	30	56

The change of resistance of *Aëdes aegypti* to an 0·05% w/v pyrethrum spray with age. Each average figure is based on two determinations by the impaction method. About 100–150 insects were used in each test.

(b) The change of resistance with age to a DDT spray:

Essentially similar results to those given by pyrethrins were obtained with a DDT spray, that is, there was a progressive decrease in resistance with age. It has been noted previously that within the age range 1–4 days old the male insects are more resistant than the females to a DDT spray. In the present experiment, for which a test group of this age range was employed, the two sexes were at first of equal resistance but subsequently the males became more susceptible. Since the standard procedure gives rather erratic results with pure DDT sprays (because the insects are not stimulated into flight) this apparent change in the relative resistance of the sexes with age has not been investigated. The results obtained are given in Table X.

TABLE X.

Average age in days.	Average percentage kill in 24 hours.		
	Male.	Female.	Average.
0–4	15	16	16
2–6	52	46	49
4–8	74	48	61
8–12	81	66	74
10–14	96	63	80

The change of resistance of a culture of *Aëdes aegypti* to a spray of DDT. Each average figure is based on two determinations with 100 insects.

(c) The comparative change of resistance to pyrethrins and DDT:

A culture of *Aëdes* having an age range of 0–4 days was sprayed at intervals with both DDT and pyrethrins. It will be seen from fig. 4 that the decline of resistance to the two sprays is not dissimilar. The insects were maintained at 28° C. and 70 per cent. relative humidity and fed on sugar and water in the usual way (David, Bracey & Harvey 1944).

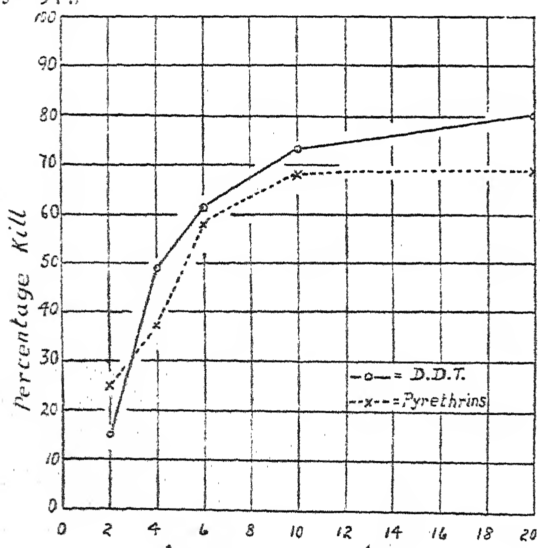

FIG. 4.—The change of resistance with age of 1–4 days old *Aëdes aegypti* maintained at 28° C. and 70% relative humidity to pyrethrins 0·01 % w/v and DDT 0·10 % w/v. The volume of spray used was 3·0 cc.

(*d*) Factors influencing the rate of decline of resistance:

It seemed possible that the rate at which the resistance of *Aëdes* to insecticides declined would be more rapid at low than at high humidities. A culture was therefore allowed to emerge over two days in rooms held at 50 and 85 per cent. relative humidity and 28° C. At the end of the first day's emergence the remaining pupae in the two bowls were pooled and re-divided between the two stock cages. The insects were sprayed in the normal way at an average age of one, two, three, five and seven days but the curves showing the average rate of decline of resistance for males and females maintained at the two humidities intersected.

It is not surprising to find that the resistance of the insects to pyrethrins decreases very rapidly when the water supply in the stock cages is not maintained. In an experiment in which the rate of decline of resistance of a test group was being followed the pad of cotton wool supplying moisture was not watered on the third day of the experiment. On the fifth day the average percentage kill was 84 per cent. instead of 58 per cent. as the previous trend of the graph suggested. Water was then again supplied and the following two days the percentage kill only increased 3 per cent. From the foregoing experiment the extreme importance of supplying the insects with a properly soaked watering pad can be appreciated. It seems possible that observed differences in the rate of decline of resistance of various cultures maintained under otherwise identical conditions may have been due to insufficient care being taken to keep the water pads fully soaked.

3. *Adult nutrition and resistance to insecticides in* Aëdes aegypti.

It has already been explained that the insects normally used for the experimental work were fed on water, sugar and raisins. However, from the practical point of view, it was of some importance to know whether the resistance of mosquitos to insecticides was increased by a blood meal.

(*a*) Preliminary experiments:

Insects emerging over a period of 48 hours during the height of the eclosion period were collected in a stock cage in the usual manner and starved for the following 24 hours. They were then divided into three stock cages and immediately fed. Insects in the first cage were given a blood meal followed by sugar and water for the males, those in the second cage were given sugar and water, while those in the third cage were given water only. The following day they were exposed in the spray testing chamber following the standard procedure. In the first test 0·066 per cent. wt./vol. and in the second test 0·10 per cent. wt./vol. solutions of pyrethrins were employed. The results obtained are given in Table XI, where each figure represents the average of two or more determinations and apply to female insects only.

TABLE XI.

Feeding treatment.	Pyrethrins 0·066% w/v.		Pyrethrins 0·1% w/v.	
	Average % kill	Average angle ± 3·7.	Average % kill	Average angle ± 4·8.
Water	19	25·5	57	49
Water and sugar	20	26·8	57	49
Water and blood	9	12·8	27	31

The effect of nutrition on the resistance of female *Aëdes aegypti* to pyrethrins. The average values of the first experiment are based on four tests, those of the second on two tests. Each test involved about 100 females.

Since a method has been developed by which the actual quantity of spray accumulated by a group of flying insects can be measured (this procedure will be described in a subsequent paper) it seemed desirable to determine whether the high

resistance of the blood-fed insects was merely an expression of the lowered flight activity. Although one day after a blood meal the insects again showed a high resistance to pyrethrins there was no evidence that they had accumulated less insecticide than the other two groups and it must therefore be concluded that blood-fed female *Aëdes* are more resistant than sugar and water-fed individuals.

A further experiment was carried out in which the change of resistance was followed over the period of oviposition and a subsequent blood meal. Insects were allowed to emerge on the first two days, on the third they were starved, on the fourth a blood meal was given, on the fifth one batch was sprayed. By the seventh day the residue had oviposited and another batch was sprayed following the standard procedure as before. The remainder of the insects were then given a blood meal and were finally sprayed on the eighth day. The results obtained with a spray consisting of 0·1 per cent. w/v. pyrethrins in odourless distillate are given in Table XII.

TABLE XII.

Condition and age of insect.	Average percentage kill in 24 hours.
Day after blood meal: 3–4 days	34
Day after oviposition: 4–6 days	73
Day after second blood meal: 5–7 days . .	52

The observed change of resistance of female *Aëdes aegypti* during the period of oviposition and a subsequent blood meal. Each average is based on two determinations on about 50 insects.

(*b*) The relative resistance of sugar and blood-fed female *Aëdes* to pyrethrins:

In a more detailed experiment the resistance of female *Aëdes* to varying strengths of pyrethrum sprays was investigated. The insects used in this experiment emerged over a period of two days. At the end of the two days emergence they were starved for 24 hours and subsequently divided into two stock cages. One batch then received a blood meal and were also provided with water while the second batch were given sugar and water. After a further 24 hours had elapsed, when the insects were between four and six days old they were sprayed. The results obtained are given in fig. 5, from which it is apparent that blood-fed females are considerably more resistant to pyrethrum sprays than sugar and waterfed insects over the whole of the dosage/mortality range which has been investigated.

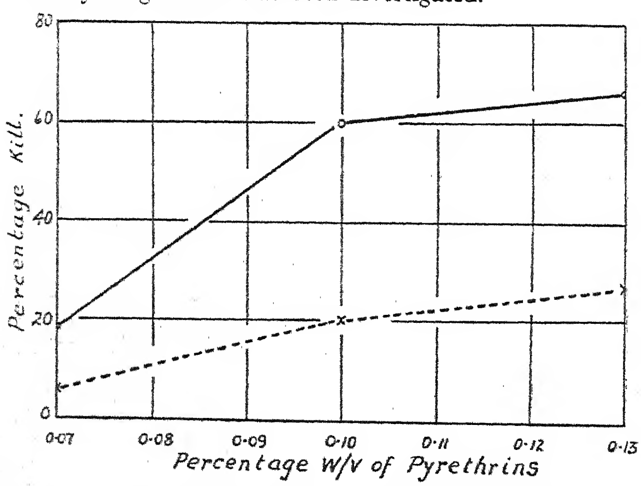

FIG. 5.—The relative resistance of sugar and blood-fed female *Aëdes aegypti* 4–6 days old to various concentrations of pyrethrins in odourless kerosene. O = sugar fed and X = blood fed.

Summary and Conclusions.

Experiments are described which illustrate some of the ways in which the results of exposing insects to a spray mist are dependent on either their behaviour or physiological state. Only fine mist dispersals with particles below 10 microns in diameter are considered and in such mists the flight movements of the insects are very largely responsible for the collisions between the insect and the droplets. An increase in flight activity leads to the accumulation of a greater number of spray droplets and consequently a higher kill. Under these conditions insecticides such as pyrethrins which exert a strong irritating action on *Aëdes* in minimal amounts are superior to DDT which does not have this effect. For practical applications under circumstances where the sprays depend on mist action to produce their effect it is advantageous to mix pyrethrum with the DDT sprays so that the maximum dose of the latter may be accumulated.

Further experiments are concerned with the relative resistance of male and female *Aëdes aegypti* to insecticides and the change of resistance which takes place on ageing or as a result of a blood meal. It is shown that the male is innately more susceptible to both pyrethrins and DDT and that the resistance of the females is higher after a blood meal. There is also a progressive decrease in resistance with age.

Acknowledgements.

We wish to thank Professor P. A. Buxton, F.R.S., and Dr. V. B. Wigglesworth, F.R.S., for their interest in this work, which has been carried out under a grant from the Medical Research Council.

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NOTES ON THE BIONOMICS OF *ANOPHELES SACHAROVI** IN PERSIA AND IRAQ.

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General.

The observations recorded in this paper were made during routine Army malaria work. They are disconnected, as military requirements did not permit of continuous observations.

*Anopheles sacharovi,** Favr, is widely distributed in Persia and Iraq, in the lower part of the hill country. Major T. T. Macan, R.A.M.C., in 1942, found that it did not occur below 500 feet, nor above 5,000 feet, above sea level. An exception to this is in the Shatt-el-Arab region, at sea level, where it is found in some numbers at isolated points in the palm belt. It is typically a stagnant water breeder, though it is also found in running water, amongst weeds; it does not appear to be confined to water with a high salt content. Adults are found in stables and houses.

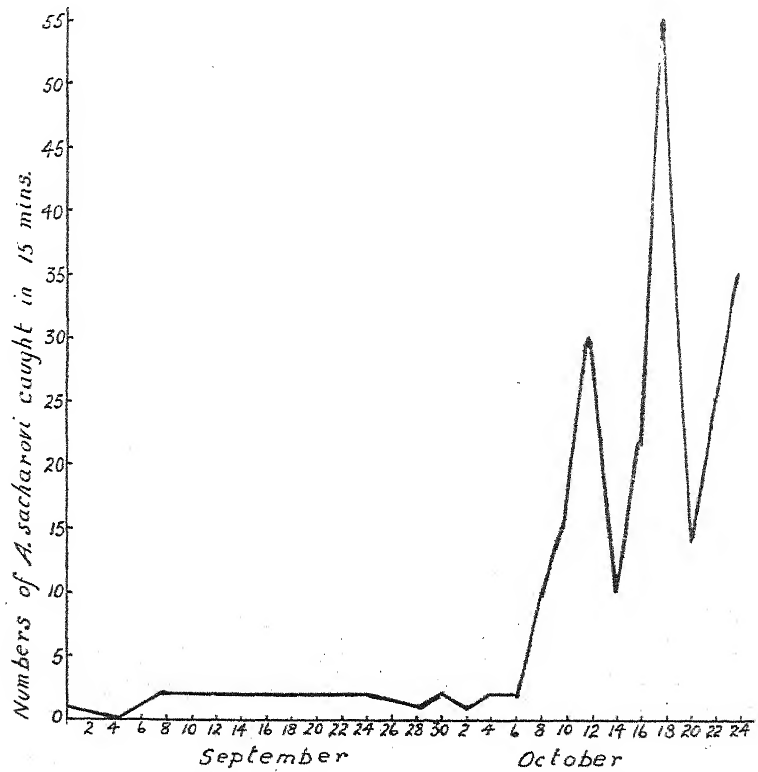

FIG. 1.—Density of *A. sacharovi* at Bakrajo (N. Iraq).

Winter Behaviour.

During September and October, 1943, observations were made on adult mosquito density in a group of villages near Sulaimaniya in northern Iraq. *A. superpictus* and *A. sacharovi,* breeding in rice-fields and irrigation waters all around the villages,

* This species is generally considered a variety of *A. maculipennis,* Mg.—ED.

were caught in stables and houses. The villages were being sprayed experimentally with "Flit", so that the catches do not represent fully natural conditions. There was no larval control.

During August (Major Macan's figures) and September, very small numbers of *A. sacharovi* were caught. At the beginning of October the numbers increased and, although varying, remained much higher until the observations ceased on 24th October (fig. 1).

This increase in the numbers found in indoor resting places appears to be correlated with the onset of hibernation. The first specimen of *A. superpictus* with a fat-body developed was taken on 29th September; two days later specimens of *A. sacharovi* showed fat-bodies. After this date both *A. superpictus* and *A. sacharovi* showed increasing development of fat.

The small numbers of *A. sacharovi* caught before 1st October make figures for the development of the ovary valueless. Of a total of 343 female *A. sacharovi* caught between 1st and 26th October, only 20 had ovaries developed beyond stage II (*cf.* Christophers, Sinton & Covell, 1928). The figures for ovary development in *A. superpictus*, shown graphically in fig. 2, indicate quite clearly when hibernation started in that species.

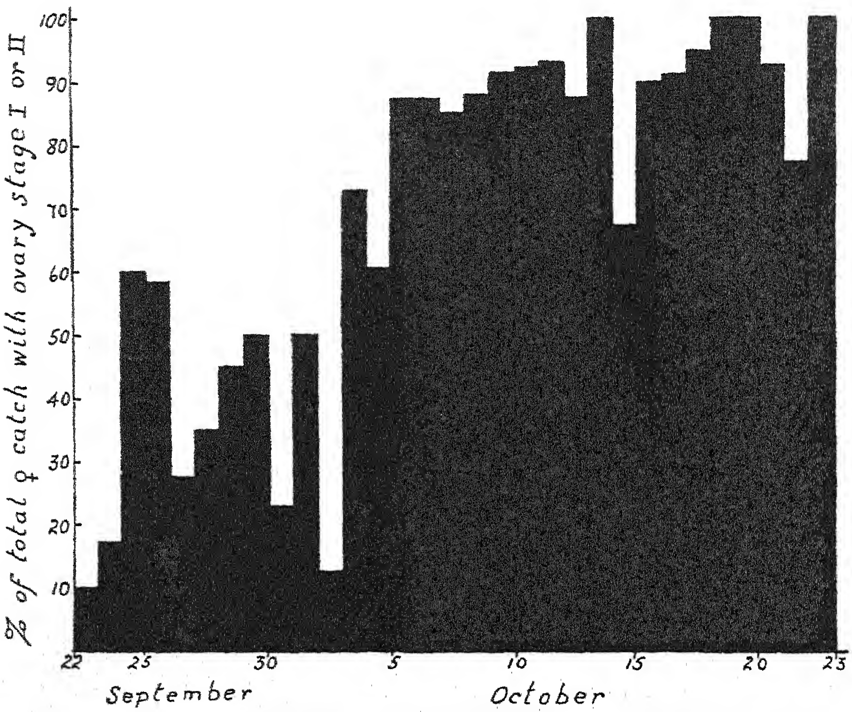

FIG. 2.—Ovary development in *A. superpictus* from Bakrajo.

Thus it appears that with the onset of hibernation *A. sacharovi* enters houses and stables more frequently. The species is normally described as completely domestic; these figures suggest that it rests less in indoor resting places during the summer than in the winter. It is unlikely that the increase in numbers is due to pre-hibernation migration; breeding places are near by, and there was a fair proportion of males in all the catches.

A rise in numbers was noted later in the winter, when hibernation was complete, at villages on the Persia–Iraq border (Khanaqin area). This area was uncontrolled and breeding was taking place along the whole length of the valley in which the villages are situated. Only three observations were possible during the winter. The estimates of density were made, on the basis of catches, by the same observer on each occasion. Figures are shown in Table I.

TABLE I.

Density of *A. sacharovi* in villages near Khanaqin.

Village.	Density of *A. sacharovi* in stables :—			
	9/xi/43	21/xi/43	4/i/44	22/ii/44
Qara Bulaq ..	200	—	500–1,000	Over 1,000
Diligan ..	—	0–5	0–5	10–20

This increase in density might be due either to a migration of mosquitos from another locality, or to an influx of mosquitos from outside resting places.

Winter Infectivity Rates.

Adults of *A. sacharovi* were collected from a number of villages in the Khanaqin area, where malaria is hyper-endemic, during the winter months. The results of dissections of these collections are shown in Table II.

TABLE II.

Dissections of *A. sacharovi*, winter 1943–44.

Month.	Number dissected.	Number with oocysts.	Number with sporozoites.
November, 1943 ..	95	0	0
December, 1943 ..	0	—	—
January, 1944	327	0	2
February, 1944	64	0	0
Totals	486	0	2

Thus the sporozoite rate for the period November, 1943, to February, 1944, was 2 in 486—0·41 per cent.

Winter Eggs.

A. sacharovi is known to produce eggs with rudimentary floats during the colder periods of spring and autumn (Mer, 1931). In February, 1944, eggs were obtained from this species showing well-developed floats ; a brief description of these eggs is given below.

Length : 0·67 mms.
Breadth, including floats : 0·18 mms.
Breadth of floats at widest part : 0·037 mms.
Number of float ridges : 9.
Intercostal membrane : Rough, with coarse reticulations.
Pattern : Typical *A. sacharovi* pattern.

Twenty-two egg batches were obtained from adults caught in the Khanaqin area of north-east Iraq, where winter temperatures are low. In every batch all the eggs showed the characters detailed above. A few egg batches were obtained from *A. sacharovi* caught at the same time of year in the warmer Shatt-el-Arab region; in these the float was not a constant character on all the eggs, neither was the float, when present, as well developed.

Only a few adults were reared from eggs with floats, owing to the adverse conditions in which the larvae developed (the adults were caught in Persia, the eggs laid in Baghdad, while the larvae pupated in Cairo). The larvae and adults differ from the description given by Hackett and Missiroli (1935) in the following details:

Fourth-instar larvae (7 specimens)
Hair No. 1, segment II: 8 branches, slightly flattened.
Hair No. 2, segments IV and V: 5 to 8 branches.

Adult (8 specimens)
Wing fringe: Uniformly dark.
Thorax: Uniformly golden-brown.
Wing spots: Not conspicuous.
External spine of claspette of male: Round-tipped (two specimens).

Relation to Malaria.

In Europe the presence of *A. sacharovi* is always associated with a high endemicity of malaria (*cf.* Missiroli, 1938). This is also true, in general, for Iraq and Persia. Villages in which *A. sacharovi* was found, even at densities of 1 to 5 per stable, normally had autumn spleen rates of between 60 and 100 per cent.

It is therefore worth recording that in one area of north Persia, *A. sacharovi* (identified by eggs) was found in association with a much lower endemicity of malaria than that described for other parts. This area lies to the south-west of Teheran, extending about 50 miles west and 25 miles south of the town. Details of spleen rates and mosquito density are given in Table III.

TABLE III.

A. sacharovi and malaria in North Persia.

Village.	Date.	Density of *A. sacharovi* per house or stable.	Spleen rate.	Parasite rate.
Yangi Imam	1/viii/43	1–5	6/29 = 20%	No record
Hisarak	1/viii/43	5–10	11/39 = 28%	4/20 = 20%
Kinarigird	8/vii/43	More than 10	3/12 = 25%	No record

This lower endemicity is the more remarkable for the fact that *A. superpictus* was also found at Kinarigird. The low spleen rates might be thought to be due to a short season, by reason of the altitude and latitude. This is unlikely; much higher spleen rates and larger spleens were found at the same altitude some 100 miles further north, in the presence of only *A. superpictus* and *A. maculipennis* var. *typicus*.

In these villages the breeding places were always small and very localised, and the distribution of the mosquitos through the villages was also localised. *A. sacharovi* is normally a strong flier, and the reason for this patchy distribution is not understood.

Summary.

An increased indoor population of *Anopheles sacharovi* at the start of hibernation is recorded.

Figures are given for dissections of *A. sacharovi* during the winter months, showing an infectivity rate (sporozoites) of 0·41 per cent.

Eggs of *A. sacharovi* laid at the end of hibernation are described.

An account is given of an area in Northern Persia where *A. sacharovi* is present in association with a lower endemicity of malaria than is usual.

We are indebted to Lt.-Col. D. N. Keys, R.A.M.C., Major J. Yofe, R.A.M.C., and Major R. Hillman, R.A.M.C., for their interest and help in these observations.

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THE HIBERNATION OF *MYZUS PERSICAE*, SULZER, AND SOME RELATED SPECIES, INCLUDING A NEW ONE (HEMIPT. APHIDAE).

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Myzodes, Mordv., 1914, type *Myzodes tabaci*, Mordv. (= *Aphis persicae*, Sulzer) is a synonym of *Nectarosiphon* Schouteden, 1901 (nom. nov. for *Macrosiphum*, Del Guercio, 1900, nec Passerini, 1860). Following Baker's 1920 Generic Classification, *Aphis convolvuli*, Kalt. (which clearly is *Aphis persicae*, Sulzer) is the type of *Macrosiphum*, Del Guercio, and therefore of *Nectarosiphon* Schouteden, a subgenus of *Myzus*, Pass.

Myzus persicae, Sulzer.

Since Buckton (1876) published his account of the biology of *Myzus persicae*, Sulz., it is generally accepted that this species hibernates in the egg stage on peach and nectarine. Huckett (1925) and Theobald (1926) found eggs of this species on cabbage, and the latter also records hibernation and the very early hatching of the eggs on *Daphne;* these observations have not been confirmed. Volkart (1939) observed oviposition on *Rosa* in Germany and Gorham (1942), quoted by Jacob (1944), on *Prunus nigra* in Canada.

It does not follow that if eggs are laid on a certain plant the species hibernates on that plant. The following observations illustrate this amply. In late summer and autumn alate gynoparae fly from the summer hosts to a number of *Prunus* species, where they deposit larvae on the underside of the leaves. I have observed this since 1936 on *P. persica* Batsch, *P. armeniaca* L., *P. serotina* Ehrh., *P. padus* L., *P. domestica* L., *P. insititia* Juslen, *P. mahaleb* L., *P. spinosa* L., *P. avium* L., *P. cerasus* L., and a number of unidentified ornamental species. On all these species, the larvae of the oviparae find suitable food for normal development, and they develop into the conspicuous brick-red oviparae, with the middle part of the body much darker to blackish-red. It even looks as if the gynoparae show no great preference for any particular species of *Prunus*, but are satisfied with the first tree of any of these mentioned. When only *P. serotina* was available, I counted over 20 gynoparae, with larvae, per leaf.

Some time after the gynoparae, the males leave the summer hosts for the winter hosts to fertilise the oviparae. Though the males seem decidedly to prefer *P. persica*, numerous specimens can be found on all the others. They copulate with the oviparae, often on the branches, and the hibernating eggs are laid in sheltered places, mostly on older branches or the trunks. These eggs of *Myzus persicae* regularly hibernate on quite a number of *Prunus* spp. Oviparae occur on *Rosa*, too, but whether they lay fertilised eggs, I do not know.

On the various *Prunus* spp. the eggs hatch normally in the spring, but in the Netherlands most of the larvae only reach maturity on *P. persica*; on the other species the larvae soon die. Even on *P. armeniaca* I have never seen a larva reach maturity, so that it seems possible that some of the authors who record hibernation in the egg stage on nectarine based their conclusions on the fact that in the autumn eggs are laid on this tree. It would appear that there is an essential difference between the hibernation of the eggs and the hibernation of the species in the egg stage. Whether a plant is suitable for such hibernation depends primarily on whether such a plant suits the fundatrix during her development. The observations by Huckett

and Theobald may be correct, though they are certainly exceptional. I have found oviparae on *Tanacetum vulgare* L., and it is likely that they will be found on many more herbaceous and woody plants, but such records probably do not indicate that the species hibernates as eggs on such plants. Theobald's notes on the hibernation on *Daphne* may relate to another species of Aphid.

It surprised me when I discovered reddish oviparae, similar to those of *Myzus persicae*, laid eggs on *Dianthus deltoides* L., and that in the following spring the larvae from these eggs developed into fundatrices. More generations developed on this host in the summer of 1936, and the species behaved quite normally until soon afterwards it proved to be impossible to transmit apterae of the third generation to potato sprouts, and later they also refused to live on beet and tulips, all favourite hosts of *Myzus persicae*. The forms on *Dianthus* were always red or reddish, while in *Myzus persicae* on potatoes only the nymphs, especially those of the males, are reddish. Theobald (1926) gives red as one of the colours in which *Myzus persicae* occurs, and de Jong (1929) has investigated parallel red and green varieties of this species living in Deli, Sumatra. Similar parallel colour varieties are known from a number of related species of Aphids, but usually without apparent morphological or biological differences between the colour varieties.

Myzus (Nectarosiphon) caryophyllacearum, sp. nov.

In the Netherlands, however, apterous viviparous examples of *Myzus persicae* seem to occur only in green or greenish forms, and red or reddish (*e.g.* reddish-brown) ones all seem to belong to other, though morphologically extremely similar, species. Thus the reddish "*Myzus persicae*" from *Dianthus deltoides* L., *D.* ? *asper* L., *Cerastium arvense* L., *C. tomentosum* L., *C. caespitosum* Gilib., *Sagina procumbens* L., *Stellaria media* Cyrill. and *Moehringia trinervia* Clairv., seems to be limited to this group of food-plants, and it hibernates as eggs on *Dianthus deltoides* L., *Cerastium* spp., and possibly on other Caryophyllaceae. It differs from the true *Myzus persicae* by the fundatrices sometimes having six-jointed antennae and always swollen siphunculi, by the tergum in apterous forms being slightly sclerotic and pigmented, with the siphunculi rather dark without darker apices, and by the males being always apterous. In *M. persicae* the siphunculi in the fundatrices are not swollen and their antennae are five-jointed, the apterae, unless developed below 10° C., have no pigmented tergum and their siphunculi have dark apices; the males are alate. The alate viviparous females of the species from Caryophyllaceae cannot with certainty be distinguished from those of normal *Myzus persicae*, so that at present it is not possible definitely to identify a winged *Myzus* with swollen siphunculi.

The species, which probably is Theobald's var. *cerastii* (figured but not described in "Aphididae of Great Britain" **1** p. 323), is here named *Myzus* (subgen. *Nectarosiphon*) *caryophyllacearum* sp.n.* It causes a distinct leaf-roll and a less distinct shortening of the internodes on the mentioned hosts. Because this species, locally at least, is very common and often more numerous than *Myzus persicae*, confusion of its alatae with the latter is likely to occur. As a vector of virus diseases the new species is probably unimportant, since it is oligophagous.

Myzus certus, Wlk.

A second red *Myzus*, much like *M. persicae*, was found on *Viola arvensis* Murr., until now its only known host. This species closely resembles the preceding one, as it has apterous males, a sclerotic pigmented tergum in apterae viviparae, etc.; the fundatrices have not yet been studied. Provisionally it is desirable to give this

* Schrank's *Aphis dianthi*, the colour of which, according to Schrank, is green, is the true *Myzus persicae*, Sulzer, which also lives on *Dianthus* spp.

form a separate name, *M.* (*Nectarosiphon*) *certus*, Wlk., for the males of this species refuse to copulate with unfertilised oviparae of *M. caryophyllacearum*, sp. n. This very common species causes a typical leaf-roll on *Viola arvensis*, which symptom does not develop when *M. persicae* feeds on it. Its alatae cannot at present be distinguished from those of *M. persicae*. As a vector of virus diseases of agricultural or horticultural crops, the species is probably of no importance because it will not feed on potato, tulips or beet.

The three species, the greenish *M. persicae*, the reddish *M. caryophyllacearum*, and *M. certus* are very closely inter-related, and the non-migrating species may be considered as split off from the original migrating form. Such phenomena are quite common in Aphids, where a number of non-migrating species may live on summer hosts of the very similar migrating species, forming a very defined group. The green *M.* (*Nectarosiphon*) *ajugae*, Schouteden, also belongs to the group of *M. persicae*, etc. *M. ajugae* is monophagous. It folds the leaves of *Ajuga reptans* L. upwards to form very conspicuous pseudo-galls, in which all the forms develop. All forms, including the oviparae and apterous males, are green. The species hibernates as eggs on the young shoots, more rarely in the old pseudo-galls. Fortunately, all the forms can be identified provided that material of the corresponding forms of the species mentioned above is at hand. The species in the Netherlands and probably everywhere is rather rare, so that confusion of its alatae with those of *M. persicae* would not influence to any serious extent statistical data on the flight of *M. persicae* obtained by trapping.

From the observations which I have so far been able to make, it would appear that it is only on *Prunus persica* that *M. persicae* can hibernate as eggs. Those forms of which the hibernation as eggs on herbaceous plants was studied are different systematic units which are here considered Linnaean species. The theory offered for their origin premises the probability that what at present is comprehended as *M. persicae*, may consist of several entities with differences in biology and different capacities as to the transmission of virus diseases.

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THE CONTROL OF TRYPANOSOMIASIS BY ENTOMOLOGICAL MEANS.

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(Plates I and II and Maps 1–3.)

CONTENTS

One of the most extensive sleeping sickness areas in West Africa extends across the upper reaches of the Volta Rivers and includes the north of the Gold Coast and parts of the Ivory Coast, French Sudan and French Togoland. Over an area of 30,000 square miles, with about 1½ million inhabitants, an infection rate above 5 per cent. was recorded in 1938. Considerable areas of lesser infection surround this main epidemic. This paper reviews the effect of such an epidemic on the agricultural population, and records methods of entomological control that were undertaken in the Gold Coast. Eradication of the local vectors, *Glossina palpalis*, R.D., and *G. tachinoides*, West., was finally achieved. The effects of this both on the disease and on local agricultural development are discussed and contrasted with the results of a mainly medical attack on the problem in the neighbouring French territory.

PART I.—THE PROBLEM

The Country and the Distribution of *Glossina*.

The investigations and experiments described in this paper took place in the Inland Savanna Forest zone of the Northern Territories of the Gold Coast. This zone is subject to an extreme climatic variation between the dry and wet seasons. The dry season lasts for five months, from November to March, during which there is practically no rainfall and the mean monthly relative humidity is constantly below 55 per cent., falling to 30 per cent. during the extremely dry period of the Harmattan wind, December–February. During the dry season the maximum shade temperature does not fall below a monthly mean of 95° F., and towards the end of the period it reaches a monthly mean of over 100° F. The rainfall varies from 40 to 53 inches in different localities (long period averages) and is concentrated mainly in the four months June–September. During the wet season the relative humidity rises to 75 per cent.—80 per cent. monthly mean, and the maximum temperature averages 85° F.

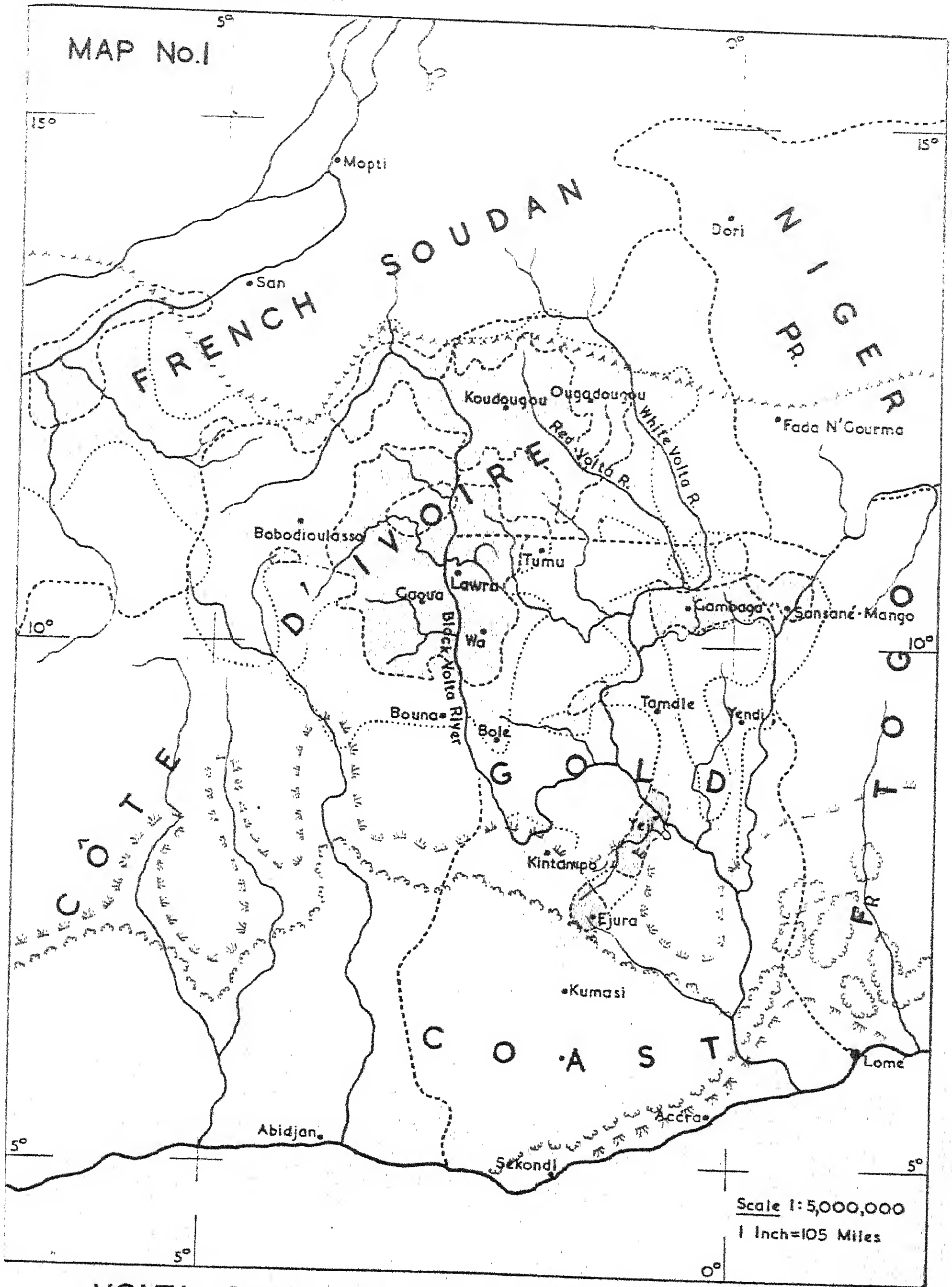
It is a country of dry savanna woodland drained by the Black, Red and White Volta rivers and their tributaries. Wherever these rivers hold permanent water, or do not dry up for more than two or three months of the year, the banks are clothed with evergreen vegetation ranging from dense, high, gallery forest along parts of the Voltas to a low, mixed evergreen and deciduous fringing forest on the smaller streams. This riverine vegetation is the habitat of *Glossina palpalis* and *G. tachinoides*, which are, consequently, widespread throughout the savanna zone except in certain localities. The exceptions occur in the most heavily and the most thinly populated parts of the country. In the very heavily populated areas in the north-east, where the density is over 200 persons per square mile, the agricultural and domestic activities of the people have so reduced the riverine vegetation that it can no longer harbour tsetse; or at most *G. tachinoides* persists in a few places. In the uninhabited parts *G. palpalis* is absent. In the thinly populated regions (10 per square mile), this species is found only at places where a village or a well-frequented road is in close contact with suitable habitat. Even here the distribution of *G. palpalis* is limited to the close vicinity of the village or road. *G. morsitans* (subspecies *submorsitans* Newst.) occurs only in uninhabited or thinly inhabited country (below 15 persons per square mile) where the larger game animals are abundant and little disturbed. In the Gold Coast this species covers 23,000 square miles, or 57 per cent. of the Inland Savanna Zone. The vast, sparsely populated central and southern regions of the Northern Territories form the main fly-belt of *G. morsitans*.

Because of their distribution along rivers and around permanent water-holes throughout the populated parts of the Northern Territories, *G. palpalis* and *G. tachinoides* come into constant and intimate contact with man and domestic stock. Consequently these two species are, from opportunity, the most important vectors of animal and human trypanosomiasis.

G. morsitans, with its preference for game and absence from well-populated country, is of less immediate importance in the problems of trypanosomiasis. This species, however, acts as a serious check to the development of thinly populated regions and is a constant menace to agricultural communities where these adjoin or are surrounded by *G. morsitans*-infested country.

The Extent and Significance of Trypanosomiasis.

The most extensive areas of serious sleeping sickness in the Gold Coast lie in the Inland Savanna Zone. The two largest of these—one in the Mamprussi district in the east, the other in the Lawra-Tumu district in the north-west—had been known for a number of years, and so were chosen as the locations for the experiments on control.



VOLTA BASIN SLEEPING SICKNESS EPIDEMIC

Distribution of Sleeping Sickness

Areas with heavy infection rate, above 5%

Areas with light

Vegetation

Thornland

Savannah Woodland

Intermediate

Zones

Glossina absent except for *G. tachinoides* and *G. morsitans* along major watercourses to the south

G. tachinoides, G. palpalis and *G. morsitans*

The north-western area was the more severely infected and has therefore received most attention. It forms one corner of a pandemic extending across the upper reaches of the Volta rivers (Map 1). This is the most serious sleeping sickness region in French West Africa, with 30,000 square miles showing infection rates of 5 per cent. to 15+ per cent. surrounded by considerable extensions of lesser infection (French unpublished Reports and Maps, 1939–40).

An almost complete history of the progress of this epidemic has been pieced together. Stories gathered from the local natives, records kept by a former District Commissioner and some early French publications have been confirmed by studying the correlations of the presence of tsetse with trypanosomiasis, depopulation and the distribution of ruins.

Sleeping sickness spread up the Black Volta from the south about 1870–80, probably by way of river traffic, which was more extensive at that time. In 1905 the disease was prevalent along the course of this river as far as its northernmost bend, but was confined to villages within a mile or two of the river banks. Within this narrow zone, however, a high degree of infection was occurring and was resulting in the desertion of riverside villages for sites farther back. Trypanosomiasis had not, until 1907, appeared in localities away from the Volta. Traffic was confined to the river itself (by canoe) or to a few well-recognised trade routes. There was practically no communication between villages because of the state of lawless antagonism that prevailed at that time. The slaving forays of Samory and Babatu at the beginning of the present century started the spread of trypanosomiasis away from the main rivers. This spread increased with the pacification and the development of commerce consequent upon the British and French occupations of the hinterland. By about 1915 serious epidemics were appearing at many points on tributaries of the three Volta rivers, and from these the spread and the increase in severity continued. Within the Gold Coast boundaries the Kamba and Kulpawn rivers, draining most of Lawra and half Tumu districts, were the earliest foci after the Black Volta itself. From these channels the epidemic spread rapidly during the past 30 years until it finally involved the whole of Lawra, Western Tumu and Western Wa districts. Depopulation followed the spread of the epidemic, and was still in progress at the time the present investigation was started in 1938. By then 160 square miles of land along the Kamba and Black Volta rivers and a larger area on the upper Kulpawn were completely abandoned.

During 1938, 1,101 cases of sleeping sickness were admitted to Lawra Hospital, out of a population of about 40,000. This did not by any means represent the full incidence of the disease, since it is known that numbers of cases from this side of the border were receiving treatment at French centres. Field surveys in 1939, after a certain amount of tsetse control had been started, showed infection rates of 4·2 per cent., 6·8 per cent. and 6·2 per cent. over areas of 200–300 square miles in western Tumu, south-east Lawra and north-west Wa respectively. Infections up to 30 per cent. occurred in individual villages. In Tumu a 75 per cent.-infected village had been found by the medical officer three years earlier. Closely correlated with trypanosomiasis infection was a very serious decline in population. The 1931 census, a recent census taken by the District Commissioner and population figures recorded during the trypanosomiasis surveys enable an accurate estimation to be made of this. Of the above three areas, the infected parts of Tumu (upper Kulpawn River) show a 30 per cent. fall in population in the 11 years up to 1942, south-east Lawra shows a 24 per cent. fall in the eight years between 1931 and 1939, and north-west Wa shows a fall of 34 per cent. in the same period. In neighbouring, but lightly infected (0·9 per cent.), parts of Wa district a 20 per cent. rise in population has taken place in the last ten years. In French territory the epidemic has caused a very serious fall in population in the country where the highest rates of infection occurred. These localities adjoin the Black Volta opposite the heavily infected Lawra and Wa districts.

Depopulation is due partly to direct mortality from the disease and partly to the migration of survivors away from the fly-infested rivers when mortality becomes high. As cattle are an important form of wealth, their loss also contributes in deciding the evacuation. This evacuation of the river valleys not only hastens the spread of trypanosomiasis but has been found to bring about two serious secondary results. Consequent upon a great increase in the numbers of game in the depopulated areas, *G. morsitans* started to spread in eastern Lawra in 1939, from a high fly-belt in Tumu, and in the same year spread across the Black Volta from the Ivory Coast and became established on the British side of that river and along the Kamba valley. The appearance of this species, with its greater range and its independence of water, brought a further menace in an already serious situation. A worse evil resulted from the migration of the people from the neighbourhood of the rivers, which produced concentrations of population on headwaters and watersheds, the places least suitable for dense population. This was followed by the over-farming of indifferent land, shortage of water, and the lack of grazing for stock, with a consequent falling-off in the standard of husbandry and a rise in the incidence of malnutrition and diseases associated with water shortage. Around the towns of Nandom and Lawra, where much of this concentration has occurred, the population density is now 250 per square mile, far too high for the soil and type of cultivation practised. In these places yields are decreasing, extensive areas of sheet erosion can be seen, and on hillside farms the soil is nearing complete exhaustion.

On the eastern side the infected area of Mamprussi is part of an endemic extending eastwards from the White Volta across Northern Togoland into French Dahomey (Map 1). The whole area is a little over 2,000 square miles in extent, the greater part lying in British territory. Survey in 1937–38 showed a fairly uniform rate of infection, averaging 4·5 per cent. over the main area with a more highly infected (6 per cent.) central strip lying along a main trade route. The main region of infection is moderately populated, hilly country with numerous swift streams infested throughout with *G. palpalis*, and with *G. tachinoides* and *G. morsitans* also present over much of the terrain. This endemic is isolated by densely populated, almost fly-free country to the north, and by almost uninhabited, flat, open savanna to the east and south. Localised areas of sleeping sickness occur in these surrounding zones, but the infection rates rarely exceed 2 per cent. In the densely populated northern zone these outbreaks are situated on the periphery, where a thinning population is in contact with the Red or White Volta rivers, the courses of which are largely uninhabited. The reverse conditions maintain the disease in the thinly inhabited zone. Here it occurs wherever an island of high population is located close to one or other of the large rivers.

In Mamprussi the widespread prevalence of trypanosomiasis is associated with considerable depopulation. There is a marked similarity to the trends in the Lawra–Tumu area. In the central strip of 6 per cent. infection a 32 per cent. fall in population occurred between 1931 and 1939. In the areas of 3–5 per cent. infection the population decline varied from 13 per cent. to 27 per cent. in eight years. In the lightly infected parts (below 2 per cent.), population rises of between 3 per cent. and 7 per cent. have taken place. In the fly-free area to the north the population increased by 30 per cent. in the same period.

Complete depopulation has resulted along 60 miles of the White Volta north of the Gambaga scarp, and the numerous ruins show that this has taken place within the past 20–30 years. Confirmation comes from a map of the district dated 1909, showing villages in the sites now devoid of habitations except empty ruins. Here, and also in the central and southern parts, a very considerable increase in *G. morsitans* has followed the depopulation. Surveys in 1930 and in 1938–39 showed that this species has trebled the area it occupied and increased at least fivefold in density between these dates.

As the present investigation proceeded it became more and more evident that small-scale measures, even though they might relieve the present danger of trypanosomiasis, would be only a partial and therefore unsatisfactory solution to the problems. Measures effecting a high degree of tsetse control, complete eradication if possible, were considered essential. Furthermore, control measures needing upkeep add both to the cost and to the complexity of any policy embracing large areas. Therefore the permanent reclamation of tsetse-infested country has been an ideal to the attainment of which much attention and research have been devoted. This ideal was not too high. There was the example of the prosperous, heavily populated north-eastern corner of the Gold Coast, where the people's own activities in their search for firewood and building poles and their cultivation of every available swamp and stream-side had driven back the tsetse to the thinly populated margins of their country. The same thing, on a smaller scale, was observed in other localities which were always centres of high population and prosperity. The conclusion was obvious. Just as the economic consequences of trypanosomiasis epidemics are more far reaching and possibly more disastrous than the direct losses in life and health, so the most satisfactory results will never be attained by concentration on the disease alone and neglect of its basic causes. Successful control must be based on the widest possible considerations of biological, economic and social factors.

Part II.—Protective Clearings and Their Uses.

Definition and Work Undertaken.

Vegetation clearing for the control of *Glossina* can be of two kinds: eradicative clearing, of which the object is the complete removal of the fly; and protective clearing, aimed at breaking the fly-man or fly-cattle contact at certain definite points where the transmission of trypanosomiasis is suspected to be taking place. In the latter type of clearing the main fly-belt remains untouched at distances varying from a few hundred yards to half a mile or more from the selected points, according to the standard of clearing laid down.

The early work in the Gold Coast was confined to the making of protective clearings. The first organised work was started in 1928 for the control of bovine trypanosomiasis on the Eastern Cattle Route (Pomeroy & Morris, 1932). Along the northernmost 70 miles of this route, clearings were made at six places, where it crossed rivers heavily infected with *G. palpalis* and *G. tachinoides*. All shrubs and trees on the banks were cut for a distance of half a mile along the river on each side of the crossing, and for a width of 20 yards on each bank. Subsequent observation showed that both species of tsetse passed through such clearings freely in both wet and dry seasons, but that the fly incidence in the clearings averaged only 10 per cent. of that in the neighbouring uncleared fly-belt. At one river, the Nasia, the mile of clearing completely eliminated *G. palpalis*, although *G. tachinoides* remained in undiminished numbers along the uncleared river. The result of these measures was a 63 per cent. fall in trypanosomiasis (mainly *Trypanosoma vivax* and *T. congolense* types) in the cattle passing down this section of the route during the year following clearing. The same rate of reduction was maintained in the next year.

Clearings for the control of human trypanosomiasis (carried by *G. palpalis* and *G. tachinoides*) were started in 1930 on a tributary of the Volta at Makongo. To ascertain the minimum of clearing which would appreciably reduce fly incidence, different lengths of clearing from 200 yards to 440 yards were made. At the same time, discrimination was exercised in the type and the amount of bush cut. Fly surveys were showing the specific nature of the fly-belt vegetation, and it was considered that in the cattle-route clearings an excessive amount of vegetation had been removed. In the Makongo experiment only the dense associations of spreading evergreen trees and shrubs along the river banks or in certain swampy areas were cut. These had been found, in preliminary investigations, to harbour breeding flies

throughout the year. Only a few months of observation were possible after the completion of these clearings, but this showed the variability of results according to the species of fly, the season and the nature of the fly-belt. A 440-yard clearing in the continuous riverine fly-belt resulted in a dry-season reduction in incidence (measured against comparable catches in uncleared fly-belt) of 5/6 in the case of *G. tachinoides* and 4/5 in *G. palpalis*. As soon as the rains started the number of flies in the clearings increased, so that the reduction in June was only 2/3 and 3/4 for the two species respectively. The clearing of two isolated *G. palpalis* fly-belts of *Berlinia heudelotiana-Raphia vinifera* association in swamps resulted in the virtual elimination of the fly, only an occasional female being caught near a water-hole in one of these clearings during the following three months. Equally important was the fact that this clearing resulted in the permanent alteration of the plant community. The *Berlinia-Raphia* fly-belt never re-established itself, but was replaced by a dense, low association of grass, herbs and creepers. Visits eight years later confirmed this.

Unfortunately the tsetse research work was stopped in 1931, but sufficient experience had been gained for the formulation of a modified clearing technique involving the removal of only the dense, evergreen vegetation within the banks of fly-infested rivers, all tall, clean-boled trees being left standing. This reduction in the amount of vegetation cut had several objects. It effected a considerable saving in labour, which enabled an increase in the length of clearings around important points. It saved the large trees, valuable for timber and shade. It obviated a tendency, which had been observed in wide, complete clearings, for men and animals to wander off to the uncleared river when resting or bathing during the heat of the day.

This modified clearing technique was put into operation on a large scale by Captain J. L. Stewart, and resulted in the eradication of *G. palpalis* and *G. tachinoides* from a large area around the veterinary farm at Pong Tamale (Stewart, 1937).

In 1935 and 1936, owing to the high incidence of sleeping sickness found in Mamprussi District, a large number of short, complete clearings of the old type were made throughout the district by the medical officers, using communal labour. Altogether 190 such clearings were made, their average length being 400 yards. The writer, on his return to the Gold Coast in 1937, made a close study of the effect of these clearings.

In 1939–41 clearings were made, mostly by communal labour, over an area of 1,500 square miles of the heavily infected Wa and Lawra districts, employing the modified clearing technique involving the removal of only specific vegetation types along the river banks. The minimum length of clearing was 880 yards, but in many places, where the support of the people was good, clearings of a mile or more were made. In the less populous parts, which frequently happened to be localities of high trypanosomiasis infection, the local people were too few or too weak to do the work, and paid gangs had to be employed. (This showed the great weakness of communal clearing as a means of combating serious trypanosomiasis outbreaks.) Altogether 126 clearings were made, with an average length of 1,330 yards. The clearings were sited so to render fly-free as great as possible a length of river around each village.

In 1941 clearings for the eradication of *G. palpalis* and *G. tachinoides* were started on a large scale in Lawra district, with paid gangs. This project has now covered the greater part of the district, linking up and consolidating all the previous communal clearings. These operations will be the subject of the third part of this paper.

The application of protective clearings over 1,200 square miles of South Mamprussi and 700 square miles of Wa, and the early work done in Lawra have enabled a critical study to be made of the effects of this method of fly control. The results and conclusions will be dealt with in the sections which follow.

Effect on *Glossina*

In this paper the estimation of the prophylactic value of clearings is the primary object. As *G. palpalis* and *G. tachinoides* are both important vectors of human trypanosomiasis, the effect of clearing on the incidence of both species together will be discussed, except where there is a marked difference in their behaviour. The amount of man-fly contact is the significant factor, and this can be accurately measured by standardised catches made by fly-boys over periods of a year or more.

Fourteen of the clearings in Mamprussi were kept under continuous observation by teams of fly-boys for two years, from September, 1937, till September, 1939. Catches were made for equal periods in each clearing and in the neighbouring uncleared fly-belt for 4–8 days every month. For the sake of comparison in the analyses all catches have been standardised to 10 flyboy-days per month. The clearings were all in a similar type of fly-belt, evergreen fringing forest forming a continuous, dense canopy along streams over undulating sandstone country. *G. palpalis* was present throughout, but *G. tachinoides* appeared only on the lower ground where the vegetation was more open. Table I summarises the results for the whole period of 24 months, giving total catches of 10 flyboy-days per month in both the fly-belt (control) and the clearing, and the percentage reduction in man-fly contact for each locality. In this table and in subsequent discussions the figures given for the clearing lengths refer to the whole clearing. Fly observations are always made about mid clearing, which implies that the flies encountered have travelled at least half the length of the clearing.

TABLE I.

Protective clearings in S. Mamprussi District.
Total catches in fly-belt and clearing for 24 months, October, 1937-September, 1939, and mean reduction (per cent.) for whole period.

Locality.	Length of clearing in yards.	*G. palpalis*			*G. tachinoides*			Total number of flies.		
		Fly-belt.	Clearing.	Reduction.	Fly-belt.	Clearing.	Reduction.	Fly-belt.	Clearing.	Reduction.
Tundi ..	200	3,131	2,598	17%	4,086	3,955	3%	7,217	6,553	9%
Kpabagu ..	250	2,905	1,224	58%	153	130	17%	3,058	1,354	56%
Bongeda ..	300	1,886	1,196	37%	707	947	−33%	2,593	2,143	17%
Soyeu ..	320	695	410	41%	—	1	—	695	412	41%
Pusigbinni ..	350	2,840	1,528	46%	8	11	—	2,848	1,539	46%
Bumbazio ..	400	5,516	2,059	63%	272	132	51%	5,788	2,191	62%
Zogilligu ..	500	1,847	510	72%	27	10	63%	1,874	520	72%
Sameni ..	600	3,968	431	89%	1,714	250	88%	5,682	636	89%
Bimbago I ..	600	3,258	877	73%	6	1	—	3,264	878	73%
Boyinni ..	650	3,610	688	81%	271	89	67%	3,881	777	80%
Boku ..	800	3,781	1,208	68%	200	124	38%	3,981	1,332	67%
Bimbago II..	1,200	3,258	522	84%	6	2	—	3,264	524	84%
Jowani ..	1,760	823	258	69%	3,037	304	90%	3,860	562	83%
Nagbo ..	1,760	1,569	151	90%	57	24	58%	1,626	175	89%

Clearing effected a consistently greater reduction in *G. palpalis* than in *G. tachinoides*, with the one exception of Jowani. Here, however, the numbers of *G. palpalis* are considerably less than elsewhere, and it can be seen from the catches of *G. tachinoides* in other localities that the effect of clearing is less marked when the number of flies is small.

Considering both species of fly there is a very marked relation between the length of clearing and its effectiveness. This is demonstrated in figure 1, in which percentage fly-reduction is plotted against the length of clearing. A hypothetical curve of fly-exclusion has been drawn in. Allowing for the wide area of country covered in these observations and the variation in local conditions, the closeness of the observations to the curve is striking.

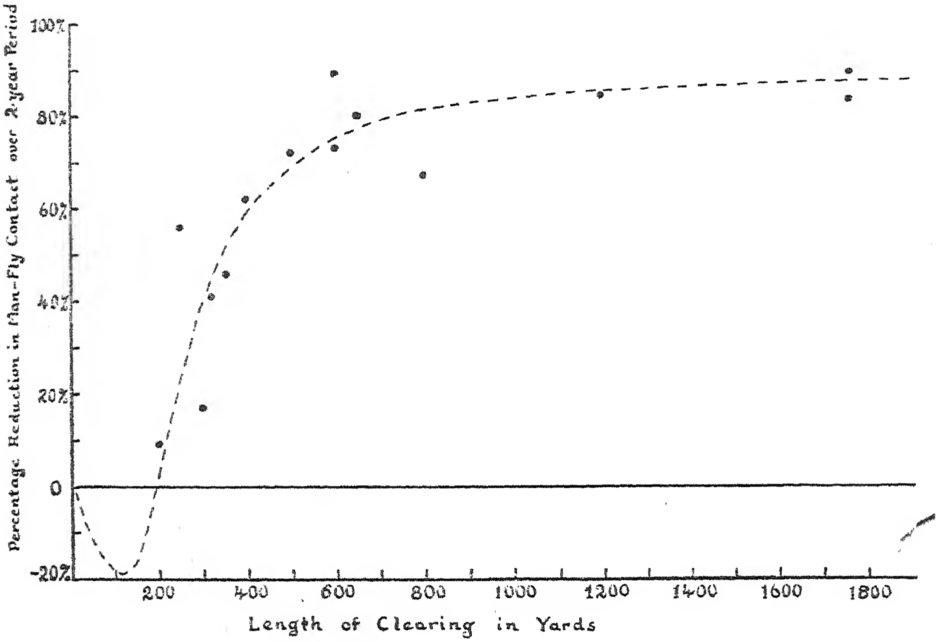


FIG. 1.—Effect of length of clearing on reduction of tsetse incidence (*G. palpalis* and *G. tachinoides*).

The curve has been extended to show an increase in fly incidence in clearings less than 200 yards long. This is in accordance with observed fact. Short clearings tend to increase rather than to reduce fly-man contact, as they reproduce the exact requirements for a tsetse's feeding ground—a clear, open space with good visibility, adjacent to the dense bush of the breeding ground. The length of clearing in which an increase of fly-incidence occurs depends on the species of tsetse and the climate of the region. In Uganda, Gibbins found that 440 yards of clearing was useless against *G. palpalis*, occasionally showing higher fly catches than the control, and averaging the same incidence (Gibbins, 1941). Brown, working in the same colony and on the same species, found 400-yard clearings useless (Brown, 1938). In the Mamprussi data under consideration the Bongoda clearing of 300 yards showed a 33 per cent. increase in the incidence of *G. tachinoides* over the whole period. In each of the five clearings less than 400 yards in length, which showed a certain amount of fly reduction over the whole period, an increase in fly-incidence occurred in the clearings during 2–4 months each year, and no reduction was apparent during 4–6 months. The climate here is very much drier than in Uganda, and this favours the effectiveness of clearings. In the moister forest conditions in the south of the Gold Coast 400-yard clearings would certainly be useless against *G. palpalis*, and would very probably increase the man-fly contact.

With the extremes of climate that occur in the Northern Territories, a considerable seasonal variation in the effectiveness of clearings is to be expected. This has been studied by totalling the monthly catches in fly-belt and clearing at the

14 localities, and estimating the monthly fly reduction from this. In figure 2 are plotted the monthly fly reductions, averaged for all the clearings, the total monthly fly catches in the controls, and the rainfall for the two years of observation. These figures are for *G. palpalis* only, since only for this species are the monthly numbers significantly large. There is a very marked annual rhythm in the effect of clearing, with two periods of high reduction, in December and in May, and two periods of low reduction, in the mid dry season (January–February) and in the mid rains (July–September). This latter period gives the minimum rate of reduction, only

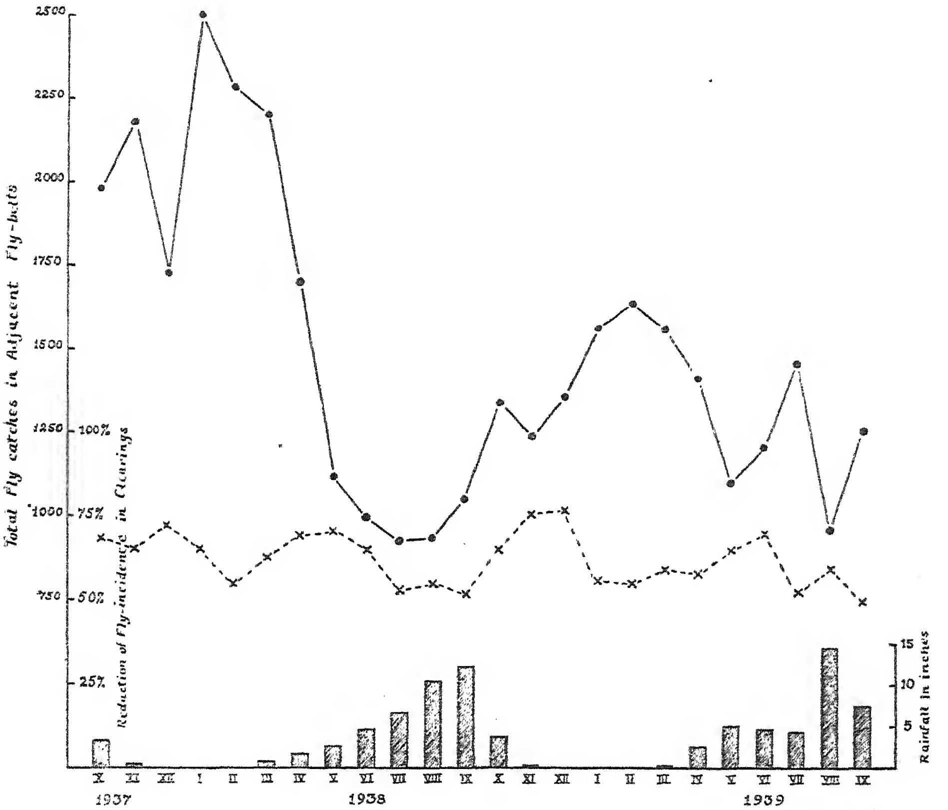


FIG. 2.—Seasonal variation in the effectiveness of clearings. The reduction in incidence of *G. palpalis* as a monthly average of 14 clearings and the monthly total standardised fly catches in adjacent fly-belts.

50 per cent., in both years. The wet season decrease in effectiveness is due to two factors: (1) the increase in humidity enables the fly to move freely and to survive for long periods in the open, which encourages a wet-season spread of the riverine species of *Glossina* along the water-courses, accompanied and aided by the colonisation of temporary wet-season habitats; (2) the falling-off in visibility because of high grass and dense leaf cover at this season renders the flies' hosts difficult to locate and causes hungry flies to wander far in search of food. When the rains fall off in October–November, the effectiveness of clearings begins to increase, but at the time when the maximum effect might be expected, the mid dry season, there is a very marked drop in the rate of fly reduction to a point only slightly above the mid-rains minimum. At this time of year the incidence of tsetse within the fly-belt is at its greatest. This is evidently related to the low rate of fly exclusion (increased

proportion of flies entering the clearing), but the exact reason for this has not yet been determined. It is no explanation to call it an effect of pressure within the fly-population. There are no reasons for supposing that the tsetses could be so over-crowded in the continuous riverine bush as to overflow into the inhospitable conditions of the clearing. For example, the fly incidence in the dry season of 1939 was two-thirds that of 1938, yet the drop in the effectiveness of clearing was greater. It is possible that the explanation lies in an increased activity due to hunger during the dry season. The low humidity of the harmattan season would necessitate more frequent feeds to maintain the flies' moisture content, which would force the flies to seek their hosts around water-holes or river crossings. The man-fly contact measured in this investigation is a joint function of the density and the activity of the fly. The high fly catches made in January–March might be due equally to increased activity as to high density. Discussion of this point comes outside the scope of the present paper.

G. tachinoides shows a seasonal rhythm similar to that of *G. palpalis*, but with a more extreme variation in its reaction to clearings, which is due to its entering clearings more freely during the wet season. The maximum exclusion (mean for all clearings) was 70 per cent. in the early dry season ; the mid-rains minimum was 12 per cent.

The practical lesson is that clearings of the type under consideration, with an average length of about 700 yards, are by no means effective barriers against the passage of *G. palpalis* and *G. tachinoides*, more especially the latter species. The degree of fly-exclusion attained is frequently far below the maximum owing to the operation of other factors more powerful in their influence on the flies' behaviour.

The observations on the Mamprussi clearings were confirmed by studies, over shorter periods, of comparable clearings in Lawra and Wa districts. Despite considerable differences in flora and terrain, the same relations between the rate of fly-reduction and the length of clearing were observed. In addition, some long clearings ($1\frac{3}{4}$–$5\frac{1}{2}$ miles) on the western side supply data that complete the Mamprussi observations. Six of these clearings were under sufficient continuous observation to give comparable and reliable fly-reduction figures, which are shown in Table II. Fly-reduction is estimated in the same way as in the Mamprussi observations, catches in mid clearing being taken as a percentage of comparable catches in undisturbed fly-belt on the same stretch of river. In the 4–5 mile clearings the rate of reduction is high, but fly-belt catches of 100–200 flies per flyboy-day could be made in these places, i.e. one or two flies were being caught daily in the clearings. This failure of even very long clearings to exclude tsetse completely is the experience of other workers. Gibbins (*loc. cit.*) found that a clearing two miles long did not prevent the passage of *G. palpalis* and that flies can travel over four miles along an open river. Symes and Vane found that clearings of 1,050 yards on the shore of Lake Victoria were not effective barriers to the passage of *G. palpalis* (Symes & Vane, 1937).

TABLE II.

Reduction in incidence of *G. palpalis* and *G. tachinoides* effected by long clearings, Lawra District.

Locality.	Length.	% Fly reduction.
Nandom Road Bridge (1939) ..	1·75 miles	95%
,, ,, ,, (1940) ..	3·2 ,,	97%
Monepelli (1940)	4·5 ,,	99·3%
,, (1941)	5·2 ,,	99·5%
Danban (1941)	5 ,,	98·0%
Nandom Road Bridge (1941) ..	5·5 ,,	99·2%

The data of Table II are plotted in fig. 3, which is an extension of fig. 1 drawn for convenience, on a different scale. The asymptotic trend, which showed in fig. 1, is very clearly brought out in this figure.

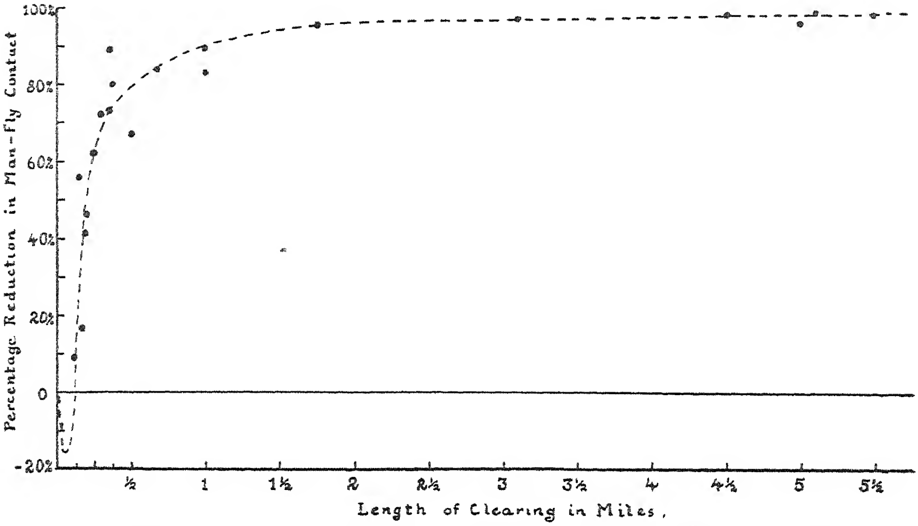


FIG. 3.—Effect of length of clearing on reduction of tsetse incidence (*G. palpalis* and *G. tachinoides*).

A combination of all the information obtained relative to protective clearings enables a summary of their effect on *G. palpalis* and *G. tachinoides* in the Inland Savanna Zone to be made in Table III.

TABLE III.

Percentage reduction in incidence of *G. palpalis* and *G. tachinoides* effected by protective clearings, Inland Savanna Zone.

Length of Clearing.	Reduction in fly-man contact.
200–300 yards	0%–50%
350–440 "	20%–70%
500–880 "	60%–90%
¾–2 miles	80%–95%
3–5 miles	98%+

Considering solely the question of fly-exclusion: Small clearings of 300 yards or less are not only useless, but are liable to cause an increase in man-fly contact; clearings up to 440 yards show a certain amount of reduction, taking the average over a year or more, but during several months in the year there is no reduction and there may even be an increase in man-fly contact; the extension of clearings up to 880–1,000 yards brings about a considerable increase in their effectiveness; but with further extension of the length of clearings the rate of increase in their effectiveness falls off; three miles or more of clearing are necessary to interrupt the regular appearance of flies in the clearing, but even five miles of clearing are traversed by a small number of wandering flies, more especially in the wet season.

The writer's conclusions from these data and from other general observations is that there are three distinct types of movement of flies into clearings. In the first place, hunger causes flies resident in the uncleared parts of the river to traverse open river banks freely in search of food. Such flies may linger in the clearing for a short while, but eventually they return to the fly-belt. This movement takes place at all times of the year, but is most marked late in the dry season, when the flies' frequency of feeding is greatest, and in the late rains, when dense, high vegetation renders hosts difficult to locate and the proportion of hungry flies is therefore high. The shorter the clearing the more readily hungry flies enter it, but they will, if necessary, traverse more than 1,000 yards of open river bank. Closely associated with, but distinct from, the hunger movement, is the movement of flies accompanying their food hosts. Such flies are not necessarily hungry; they may be replete, having fed on a host during transit; or they may be males which, in their search for females, regularly accompany hosts. In the experience of the writer, *G. palpalis* and *G. tachinoides* have been carried by men and cattle for distances up to six miles. This type of movement will take flies over much greater distances than they will traverse normally in search of food, and will bring them into clearings not only from uncleared parts of the same river but from neighbouring uncleared rivers. Season has no effect on the extent of movement of this nature, which is encouraged by the presence of herds of cattle or game or the existence of much-frequented market or trade routes. The third type of movement is caused by the tendency of *G. palpalis*-group tsetses to wander along water-courses for considerable distances. This goes on to a slight extent throughout the year, but is greatest during the rains, when it develops into a definite extension of the flies' range through the colonisation of temporary wet-season habitats. (Permanent and temporary habitats will be discussed in Part III.) This seasonal spread of the fly takes place gradually, in contrast to the short-period movements described above and reaches its maximum about October, at the end of the rains. The main lines of extension are always along waterways, which may hold no obvious fly-belt vegetation at all and yet harbour a few *G. tachinoides* or *G. palpalis* during the wet season. The full range of such seasonal extension has not yet been determined. *G. tachinoides* has been known to traverse 10 miles of open river bank in a season; the extreme range may be considerably more than this.

The efficacy of clearings in the control of trypanosomiasis will depend not only on their length but on the type of movement bringing flies into the clearings. Consideration must be given to the relative amount of each type of movement into the different lengths of clearings, and to the influence of such movement on the flies' potentiality as a vector of the disease. The writer's interpretation of the findings is that the hunger movement accounts for the majority of the flies entering clearings up to a mile in length, but is unlikely to cause them to traverse clearings of two miles or more. Hunger is responsible for the increased number of flies invading clearings in the late dry season, and in part for the increase occurring during the rains (fig. 2). Introduction by food-hosts and the wandering habit account for all flies entering clearings two miles or more in length, and for a small proportion of those entering short clearings (less than one mile). The tendency to wander increases in the wet season, and this movement is largely responsible for the lowered effectiveness of short clearings at this time. Coupled with the hunger movement, this causes the greatest invasion of short clearings during the height of the rains (fig. 2).

Considered as potential vectors of sleeping sickness, flies motivated by hunger are the most important group for building up local infection. Being resident in the neighbourhood of the cleared water-hole or road, they are liable to pick up infection and, if infected, to pass it on to a number of people. Vagrant and introduced flies, lacking these opportunities, are less likely to be of local importance. They are, however, a potent means of spreading infection, and they can, under certain circumstances, give rise to local outbreaks of short duration. Several instances of this

happening have been experienced during the work in the Gold Coast. In each case a small number of wandering flies had occupied an isolated temporary habitat in close contact with humans, where the opportunities for the spreading of infection were good. In the case of animal trypanosomiasis, vagrant flies have as many opportunities as resident flies of picking up infection, since numerous reservoirs exist in game and wandering stock as well as in the herds it is hoped to protect. All flies, then, must be regarded equally as potential vectors by the veterinarian. A few wandering *G. tachinoides* have, on several occasions, caused considerable damage by coming in contact with herds of non-immune cattle in areas extensively cleared.

On theoretical considerations, short clearings could not be expected to do more than lower the incidence of trypanosomiasis. They are traversed freely by resident, hungry flies which are potentially the most dangerous vectors. They cannot effectively break the vicious circle of man-fly-man infection because such fly-exclusion as they do, at best, exert is lowered considerably for two periods in the year. These disadvantages are overcome by the extension of the clearings to a mile or more in length, although their apparent effectiveness (percentage reduction in fly-incidence) increases very little with the extension of clearings beyond half a mile. Long clearings could be expected to bring about a much higher degree of trypanosomiasis control than short clearings, and the effect is likely to increase with the extension of the length of clearing. For not only are the disadvantages of short clearings overcome but additional points of man-fly contact are affected in long clearings. In localities of widespread and heavy infection, however, even very long clearings are unlikely completely to eradicate the disease as long as uncleared fly-belt remains in the vicinity of the towns and villages.

Effect on Trypanosomiasis.

Several large areas of the Northern Territories, with initially much the same rates of infection, have each had a different clearing method applied throughout. This has made possible the evaluation of the effectiveness against human trypanosomiasis of different clearing principles. In one of the areas, Lawra district, *G. palpalis* and *G. tachinoides* were completely eradicated by a method of selective clearing which will be described in the third part of this paper. The effect of these measures will be discussed here, to enable comparisons to be made with the results of protective clearings.

As repeated trypanosomiasis surveys have not been made in the area under consideration, the trend of the disease has been estimated from the admissions of new cases to treatment camps or hospitals. Attendances at a well-run treatment centre which has the confidence of the natives give a fairly accurate measure of the trend of trypanosomiasis incidence within a radius of 25 miles. This has been proven by a comparison of hospital admissions with survey findings by Saunders in Mamprussi (Saunders, 1938), and by the writer in Lawra and Wa. In the following discussions trypanosomiasis incidence is taken from the number of new cases admitted to hospital during the year. A year's hospital admissions show the influence of clearing measures carried out in the same year, since clearing work invariably ceases by March and its effect is immediate. A better measure would be obtained by taking hospital figures for the yearly periods April–March, i.e. after clearing had finished. This would give a fuller representation of the effects of each year's control operations, but the full data were not always obtainable for analysis in this way.

In South Mamprussi district a policy of making small clearings at all village water-holes and on rivers crossing main roads was carried out in 1935–36. The area covered was 1,200 square miles, and the infection rate was 5 per cent. The clearings, the total length of which was 44 miles, were made at 190 places, giving an average length of 400 yards per clearing. A decline in trypanosomiasis admissions to Nagpanduri and Gambaga camps, which serve the area, was apparent immediately

after the clearing had been done. Estimates by Dr. Saunders, who was responsible for these camps and for field surveys, and by the writer, agree closely in giving the amount of reduction in trypanosomiasis incidence during the first four years after clearing as follows: Reduction for one year, 6 per cent.; for two years, 15 per cent.; for three years, 30 per cent.; for four years, 35 per cent. Mass treatment over the whole area was carried out in the fourth and fifth years, and was followed by a marked increase in the amount of trypanosomiasis reduction which reached 67 per cent. by the sixth year. Further reduction beyond this point took place very slowly, so that at the end of nine years the total reduction was only 75 per cent., despite the fact that a second mass treatment had been done and additional long clearings made around the two treatment camps.

Small clearings, then, made consistently over a wide area, can effect a partial control of trypanosomiasis, reducing the incidence of the disease by as much as 35 per cent. without the aid of additional control measures. The disease, however, tends eventually to become stabilised at a lower incidence. The reason for this is that water-holes and main-road crossings are by no means the only localities where the transmission of trypanosomiasis takes place. Besides these obvious danger spots there are innumerable other sources of contact between man and tsetse. Every village has a series of paths radiating from it, leading to farms and neighbouring villages. Wherever these paths pass through fly-belt there are points of regular man-fly contact where infection is likely to take place. Market paths and trade routes, which by no means always follow main roads, are especially important because of the regularity with which they are used by large numbers of people. Regular man-fly contact occurs also where farms adjoin streams and at cattle-watering places. Occasional contact with the fly is apt to occur in most of the rural occupations, such as the tending of flocks and the gathering of firewood, fruit and herbs, or in the masculine pursuits of hunting and fishing. Occasional contact is less dangerous than regular contact in the transmission of sleeping sickness, but it cannot be ignored if the complete control of the disease is to be achieved.

The partial control effected by removing only one source of man-fly contact was well illustrated in the Bimoba area of Mamprussi. In this area the clearings, which were well done, were made only at water-holes. Now, women spend more of their time than men do at water-holes, and so a larger proportion of them would be infected there. The clearing of water-holes would therefore be expected to cause a greater immediate decrease in the infection rate of the women than in that of the men. This actually took place among the Bimobas, as is shown in the following table (taken from Dr. Saunders's Annual Report for the Trypanosomiasis Campaign for 1938).

TABLE IV.

Sex ratio of trypanosomiasis patients attending Nagpanduri camp and coming from Bimoba area of Mandated Togo, South Mamprussi.

Year.	Male attendances.	Female attendances.	Excess of males.	
			Number.	%
1934	442	428	14	2%
1935	587	542	45	4%
1936	386	326	62	9%
1937	341	271	70	11%
1938	294	201	93	18%

In South-west Mamprussi, on the other hand, where clearings were distributed indiscriminately among roads and water-holes (and many water-holes were missed), the infection rates of males and females were equally reduced during the same period.

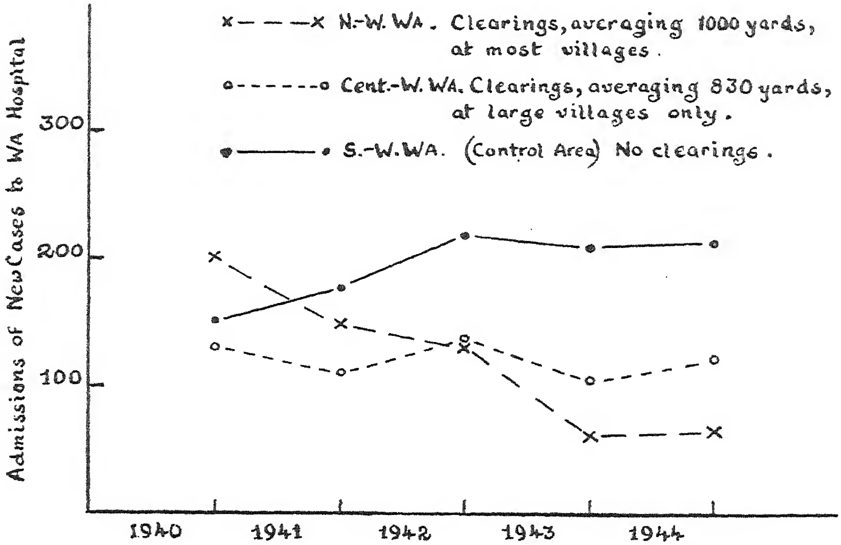


FIG. 4.—Effect of protective clearings on sleeping sickness in Wa District.

In north-west Wa district a number of long protective clearings were made by communal labour in 1940–42, with the use of a new technique involving the removal of only certain vegetation types along the river banks. These clearings were sited so as to include, in one continuous stretch, as many as possible of the water-holes and paths in the neighbourhood of each village. In 500 square miles of countryside altogether 34 miles of clearing were made, at 60 places, giving an average length of 1,000 yards. Many individual clearings were between one and two miles long. The infection rate of the area as a whole was 4·5 per cent. Hospital statistics for the years prior to clearing are not available for this area, as the home villages of the patients were not accurately recorded until half way through 1939. A study of the data available suggests that the incidence of trypanosomiasis was much the same in 1939 as in 1940. The trend of the disease from 1940 onward is shown in fig. 4. A steady decline took place during the first three years but ceased in the fourth year. The reductions were: First year, 25 per cent.; second year, 36 per cent.; third year, 71 per cent.; fourth year, 69 per cent.

In central-west Wa a similar programme of long protective clearings by communal labour was started in 1940. This area was heavily infected, over 6 per cent., the people apathetic, and the amount of fly-belt in contact with habitations extensive. Consequently, in an area of 200 square miles only 8½ miles of clearing were made, at 18 localities, averaging 830 yards per clearing. There was no appreciable reduction in trypanosomiasis in this area by the end of four years after clearing, although there were temporary reductions of 15 per cent. and 19 per cent. in the first and third years respectively. Two or three villages where the clearings were extensive and well made show reductions up to 50 per cent. Both the north-west and central-west areas had a single mass treatment in 1939. An isolated measure such as this might contribute to the immediate fall in the infection rates, but, judging from the central-west area of Wa and from other considerations, it is doubtful if it would have any lasting effect.

South-west Wa serves as a control area, since it has had neither clearings nor mass treatment. A 47 per cent. increase in the incidence of trypanosomiasis took place during the first two years of observation, after which the disease remained stable at the higher level.

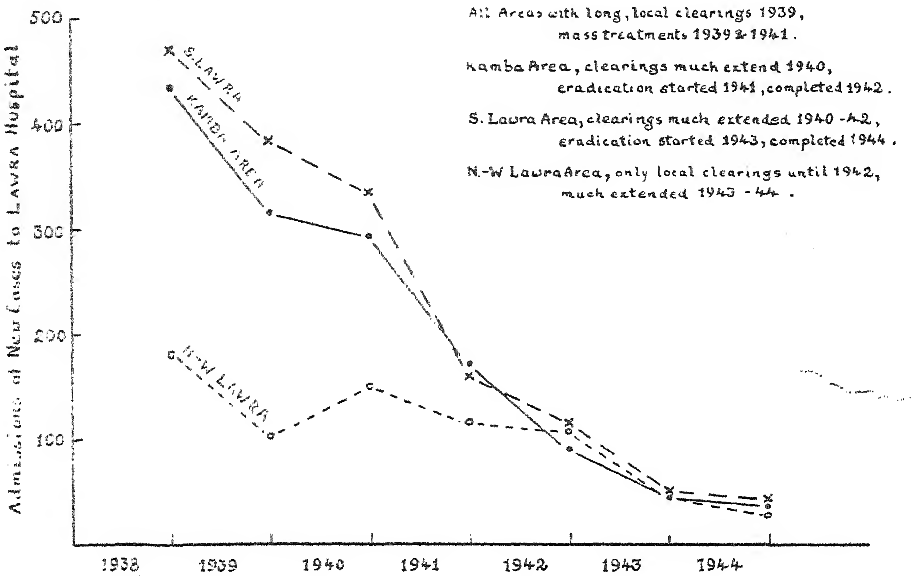


FIG. 5.—Effect of tsetse eradication on sleeping sickness in Lawra District.

In Lawra district a progressive programme of clearing was put into operation. In 1939 long clearings, minimum three-quarters of a mile, were made, but only in the most heavily infected localities. In 1940 these were extended and their number increased, so that they totalled 26 miles of clearing in 34 places, giving an average length of 1,340 yards. Selective clearing for the eradication of tsetse was started in 1941 on the Kamba River system, which drains 600 square miles, approximately half the district, and was completed at the end of 1942, amounting to the clearing of 105 miles of river. In 1942 selective clearing was extended over 250 square miles of the southern part of the district. This was completed by 1944, giving an additional 48 miles of clearing. The north-west corner of the district had only localised clearings up to the beginning of 1943, but since then clearing has been considerably extended. The tsetses were not eradicated until 1945. Mass treatment was done in certain parts of the most heavily infected places in 1938 and 1939, and over the whole area in 1941, with a repetition in the same year over the Kamba section only.

Lawra district can thus be conveniently considered in three blocks: (1) 600 square miles of the Kamba, with 105 miles of clearing; tsetse eradicated by 1942; (2) 250 square miles to the south of this, with 48 miles of clearing; tsetse eradicated by 1944; (3) 200 square miles of the north-west corner, with only local clearings up to 1942, considerably extended in 1943 and 1944, when clearings amounted to 23 miles; tsetse not eradicated until 1945. The entire district is bounded by three heavily infested fly-belts, as yet uncleared. These are the Black Volta River on the west, the Kulpawn River on the east, and the Lawra-Wa boundary river to the south.

The average rate of trypanosomiasis infection before control measures were started was about 4·5 per cent. In 1938, 1,101 cases were admitted to hospital. In 1944 the number of new cases admitted was 105, showing a 90 per cent. reduction

in six years for the whole district. The rates of reduction in the three separate areas are shown in fig. 5. In the Kamba area, with a progressive clearing programme started in 1940 and the tsetses eradicated by 1942, a remarkably smooth curve of reduction is exhibited. The amounts of reduction, year by year, are: First year, 28 per cent.; second year, 38 per cent.; third year, 61 per cent.; fourth year, 79 per cent.; fifth year, 90 per cent.; sixth year, 92 per cent. Trypanosomiasis reduction in the south Lawra area followed the same trend as that in the Kamba area, but without its consistent smoothness. It is noticeable that from the time the fly had disappeared, in 1944, the two curves run parallel. The reduction in this area by the end of the sixth year was 91 per cent. The increased rate of fall in both areas between 1938 and 1939, and between 1940 and 1941 would be due to the combination mass treatment and clearing. It is worth pointing out that in 1941 the double mass treatment in the Kamba area had a less marked effect than the single mass treatment in south Lawra. The explanation offered for this is that by 1941 a fairly high degree of tsetse control had been attained in the Kamba area, whereas there remained a considerable extent of fly-belt in south Lawra. It is reasonable to expect that the effect attainable by direct attack on the parasite (mass treatment) will diminish as the control of the vector becomes more perfect.

The data from the north-west area enable a comparison to be made between the effects of localised clearings and two mass treatments, which together brought about a reduction of 40 per cent. in four years (1938–42), and those of extensive clearings at all localities, which effected a 75 per cent. reduction in two years (1942–44). The final reduction in this area was 85 per cent. of the pre-control figures. The irregularities in the curve give it a resemblance to that of central-west Wa. The control measures applied during the first four years were evidently insufficient to cope with the situation, which involved factors tending to vary the incidence of the disease from year to year. The change in the trend of the disease on the extension of clearing in 1943 is quite obvious.

The occurrence of an annual variation in the incidence of trypanosomiasis can be seen from a study of the graphs for Wa and Lawra. The years 1940 and 1942 were certainly of increased trypanosomiasis incidence; 1944 may also have been so, though the indications are less clear. The total attendances at Wa Hospital in 1940 were above those for 1939. In Lawra the rise in the number of cases from the north-west area in 1940 is accompanied by a diminution in the rate of reduction in the other two areas. In 1942 both the control area of south-west Wa and the imperfectly cleared central area showed a rise in trypanosomiasis, that in the control area being greater. There is a decrease in the rate of reduction in the other areas, with the exception of the Kamba, where tsetse had been eradicated by the middle of 1942. This is significant. It suggests that variations in the behaviour or the abundance of the fly vector were responsible for the annual variation in trypanosomiasis.

Consideration of the data from Lawra, Wa and Mamprussi indicates that mass treatment, even if discontinuous, can increase the rate of reduction of trypanosomiasis which is being effected by clearing. It does not, however, affect the end result provided clearing is properly carried out. In the case of ineffective tsetse control the addition of mass treatment will achieve a greater eventual reduction in trypanosomiasis than will clearing alone. In the case of effective fly control, especially if this can be brought to the point of eradication, the addition of mass treatment will make no difference. The greater the effect due to clearing, the less will be the effect of mass treatment. Tsetse control, by attacking the vector, cuts off the parasite before it has entered man. Mass treatment attacks the parasite only after it is established in man. If the control of the vector can be complete (as in tsetse eradication), there will be no supply of new infections to be dealt with by mass treatment, which will be effective only in clearing up already infected

people. As these infections are no longer a danger to public health, in the absence of the vector, the subsequent effect of mass-treatment on the course of the disease will be nil.

Before summing up the results of this investigation, it is necessary to consider three important points, two general and one purely local, which mask to some extent the value of the trypanosomiasis index as a measure of the effectiveness of clearing. (1) In the West African form of sleeping sickness, due to infection with *Trypanosoma gambiense*, the course of the disease is very slow, lasting three to four years in some patients. Consequently there will be a considerable lag between the disappearance of tsetse and the complete disappearance of the disease. In view of this, the rapidity with which the local hospital attendances have been affected by the various measures of entomological control has been most gratifying. It indicates that a large number of early infections come in for treatment. (2) There will be a certain amount of introduction of cases into each controlled area by local people who have become infected in neighbouring uncontrolled areas. A great deal of movement continually goes on among the local inhabitants, from the long journeys of several hundred miles by labourers and traders who periodically visit the Ashanti forest country and even the coast, to the local movements of a dozen miles or so to markets, social gatherings, etc., or the occasional forays into uninhabited, uncleared bush for hunting and fishing. The proportion of introduced trypanosomiasis cases to locally infected cases will depend on the size of the area under consideration, the greater the area under control the smaller being the proportion of introductions. But as long as parts of the country are infected, and are visited by people from cleared country, the reintroduction of cases into the cleared district will be inevitable. (3) After the start of the work in Lawra district there occurred an invasion of *G. morsitans* into a section of the Kamba and north-west Lawra areas. This species is not affected by the clearing measures directed against *G. palpalis* and *G. tachinoides*, and it was only by 1945 that it was brought under some degree of control. Although *G. morsitans* was less numerous than *G. palpalis* or *G. tachinoides* and was in less close contact with the people, the persistence of this additional vector after the others had disappeared may have been responsible for a certain number of residual infections.

Table V summarises the effects of the different applications of clearing against *G. palpalis* and *G. tachinoides* in areas of fairly heavy trypanosomiasis infections (4 per cent. to 6 per cent. throughout). The table facilitates the drawing of conclusions on this aspect of trypanosomiasis control :—

(1) The most outstanding point is the necessity for the application of clearing processes in as many places as possible over as wide as possible an area. Both long and short clearings fail to effect any permanent reduction in trypanosomiasis incidence if applied piecemeal to a few localities only.

(2) Small clearings (average 400 yards), breaking the man-fly contact imperfectly and only at certain points around each village, can bring about reduction in trypanosomiasis up to 40 per cent. if applied consistently over a large area. The reduction is slow, 5–15 per cent. per year, and without additional measures is not progressive, the disease tending to become stabilised at a lower incidence after four or five years.

(3) An increase in the lengths of clearings to an average of 1,000 yards doubles their efficiency (a 70 per cent. reduction was attained in three years), but the tendency for the disease to become stabilised at the reduced level remains.

(4) Extension of the clearings to 1–2 miles at each village brings a further increase in the degree of control attainable which can amount to 85 per cent. It is possible that when such a degree of control is reached it might progressively increase, especially in areas of light infection, or where

TABLE V.

Summary of the effects of different methods of clearing on sleeping sickness.

Locality.	Type of clearing.	Area.	Aggregate length of clearings.	Number of clearings.	Average length.	Percentage reduction in tryps. incidence.						
						1st year.	2nd year.	3rd year.	4th year.	5th year.	6th year.	7th year.
Central-west Wa	Medium protective, at large villages only.	200 sq. miles	8½ miles	18	830 yards	15	—5	19	6			
Mamprussi ..	Small protective, at water-holes, of most villages and few roads.	1,200 sq. miles	44 miles	190	400 yards	6	15	30	35	55	67	78
North-west Lawra	Long protective, at few places with greatest infection, up to 4th year, considerably extended, 5th and 6th years.	200 sq. miles	23 miles			42	16	36	40	76	85	
North-west Wa	Long protective, around most villages	500 sq. miles	34 miles	60	1,000 yards	25	36	71	69			
South Lawra ..	Localised, long protective 1st and 2nd years. Extended to all localities 3rd and 4th years. Eradicative in 5th and 6th years.	250 sq. miles	48 miles			20	30	67	76	90	91	
Kamba River..	Localised long protective 1st year. Extended 2nd year. Eradicative throughout river system 3rd and 4th years.	600 sq. miles	105 miles			28	38	61	79	90	92	

fly-belt was neither extensive nor heavy. But as protective clearings, even when five miles long, do not completely exclude tsetse, and do not break all points of man-fly contact, they are unlikely to bring about complete control in areas of serious trypanosomiasis.

(5) The eradication of the tsetse-fly from an area causes a rapid and progressive fall in trypanosomiasis, even though the region may be bounded by extensive, uncleared fly-belt. The degree of control affected is not liable to annual variations as in the case of protective clearings. Complete control of the disease, except for introduced cases, must eventually result.

Before a final decision is made on the merits and failings of protective clearings, it is necessary that the wider and more general aspects of their effects should be considered.

Additional Considerations.

The evidence brought forward in the preceding section shows clearly that a carefully planned programme of protective clearings can effect a high degree of control of sleeping sickness, and that this is brought about rapidly. However, during the course of the investigation certain failures and certain disadvantages became apparent, and consideration must be given to these in estimating the place of protective clearings in a widespread scheme of trypanosomiasis control.

This method is unlikely to eradicate sleeping sickness for two main reasons.

In the first place, when the disease is endemic, the transmission of infection is not confined to a few definite points, but takes place generally in the bush wherever the native's activities bring him in contact with tsetse. Trypanosomiasis is primarily a rural disease, and even when the vectors are the exclusively riverine tsetses, an agricultural and pastoral people is constantly in contact with them at places other than the village water-hole : e.g. on their journeys to markets, funerals, family visits, etc. ; in farming, while tending and watering stock ; while cutting wood or gathering fruit, pot-herbs and medicines ; while hunting and fishing.

In heavy endemics it is probable that less than half the infections are acquired at the local water-holes, and not more than two-thirds in the immediate surroundings of the village. The results of the Mamprussi clearings and the sex ratio of the infected people show this.

The second weakness of protective clearings lies in the fact that they never completely exclude the fly. The extreme length of clearing necessary to cut out the fly entirely during its wet-season migrations is probably as much as 10 miles. In heavy fly-belts where one boy can catch 200–300 flies a day, the 95–98 per cent. exclusion effected by two to three miles of clearing still allows through a number of tsetses. When high trypanosomiasis infection rates exist, a few flies are sufficient, under certain conditions, to maintain the transmission of the disease.

A further source of failure arises from the habit of the riverine tsetses of forming temporary wet-season colonies in thickets or under clumps of tall trees, where they are never to be found during the dry season. These temporary foci may be at considerable distances from the river, and if close to a village, they constitute a recurrent source of danger and largely offset the effects of clearings at water-holes or river-crossings. This has been experienced during the present work, on one occasion in a firewood plantation of *Cassia*, in another case in a mango grove in a station garden.

Besides the above extrinsic failings of protective clearings there are certain disadvantages inherent in the method. The majority of these arise from the fact that, to get the maximum fly-reduction in protective clearings, the complete removal of woody vegetation is necessary. It is well known that isolated large trees or

bushes along open river banks are attractive to tsetse, seeming to act as landmarks to wandering flies and certainly affording temporary resting places. In the wet season breeding foci can form around such trees. The wholesale clearing involved in the removal of every tree and bush means the loss of valuable timber and shade trees, which grow particularly well along water-courses. The felling of large trees is a slow and difficult task compared with the removal of the more dense, low and shrubby vegetation. Their stumps are difficult to kill, and, if not killed, coppice appears, the resulting growth affording excellent cover for tsetse. The most serious disadvantage is that the complete removal of vegetation is liable to cause erosion of the river banks, which, besides being an evil in itself, often defeats the aim of the clearing by silting up the water-holes and driving the people back to the uncleared river for their water. Even without silting having occurred, the people are apt to forsake a cleared water-hole for one under trees, shade and privacy being of more importance to them than the mere freedom from biting flies. Many of the water-holes in the short Mamprussi clearings were abandoned, or partially abandoned, for the above reasons.

The final disadvantage and, to the writer, the most weighty of all, is that protective clearing is at best a palliative measure, designed to remove only the immediate and obvious danger to the population, that of the disease itself. The wider social and economic evils that follow in the wake of a serious sleeping sickness epidemic are not relieved by the removal of the disease. In a country with six months of drought the domestic and agricultural life of the people is inevitably associated with the rivers and streams that hold permanent water. These are the natural haunts of *G. palpalis* and *G. tachinoides*, and as long as this is so, the danger of trypanosomiasis remains. To make only a few isolated points along these water-courses safe does not fit in with the natural, and what should be the ideal, distribution of population. Such a policy, by concentrating man and stock at particular places, may bring on the evils of erosion, over-grazing, the pollution and exhaustion of the water supply, and an increased transmission of water-borne diseases. Moreover, stock can never be kept away from contact with the fly by small clearings, and so the raising of good herds of healthy cattle, the basis of sound agriculture and the source of much-needed protein, will never be possible while long reaches of the rivers remain infested with tsetse-flies.

The limitations of protective clearings were realised early in the present investigation, so that while the above observations and experiments were still in progress, research was being concentrated on methods for the eradication of *G. palpalis* and *G. tachinoides*. Eradication would remove most of the disadvantages intrinsic to protective clearing and would make it possible to formulate a progressive policy of widespread trypanosomiasis control that would fit in with the rural activities of the population.

Part III. Tsetse Eradication.

Principles of Eradication.

In the Inland Savanna Forest Zone, which covers the whole of the Northern Territories of the Gold Coast, the distribution of *G. palpalis* and *G. tachinoides* is exclusively riverine. Even along the rivers and water-courses the distribution is not continuous, especially during four to six months of the dry season, when resident flies are restricted in range to certain stretches of river. These localities, where breeding continues throughout the year, have been variously named "dry-season habitat", "permanent fly-belt", or "primary foci". In the wet season tsetses extend their range considerably, spreading mainly along water-courses where they occupy temporary, wet-season or "secondary" habitats. Wet-season habitats become untenable soon after the cessation of the rains, when the flies either die off

or retreat to the primary foci. In consequence the tsetse communities in the inland savanna of West Africa show a very marked seasonal expansion and contraction. This was first observed in Northern Nigeria, in the case of *G. palpalis* by Macfie (1912), and in the case of *G. tachinoides* by Johnson (1918). During the dry season, the distribution of both species is so restricted and their activity at times so low that, without an expert knowledge of their habitat, it is often extremely difficult to locate the flies at all. Indeed, the extremity of this dry-season regression led Roubaud to make the statement that in Central Dahomey *G. tachinoides* is restricted to latitude 7° N. in the dry season, from which it extends to 11° N. in the rains (Roubaud, 1921). A regular seasonal migration of nearly 300 miles is outside modern conceptions of the behaviour of tsetse, yet Roubaud's observation was quoted by Zumpt in 1936.

The seasonal expansion and contraction of the tsetse's range led the writer to the consideration of the tsetse community of a whole river system as the natural biological unit which would be most vulnerable at the time and in the localities of its greatest contraction. The concentration of attack on these points would produce the maximum results in control. If the fly could be eliminated from the primary foci over an area sufficiently large to preclude wet-season invasion from outside, the whole community should eventually die out.

The first attempt was based on the observation that breeding was confined to extremely localised areas on rivers holding continuous, uniform fly-belt vegetation. Yard-by-yard pupa searches along several miles of four separate rivers, situated on the east and west sides of the Northern Territories, had shown that only certain very limited points along the rivers were chosen as sites for the deposition of puparia. The conditions required were shelter from sun and wind, a loose friable soil and the presence of either surface or subsurface water. In the dry season of early 1939 all the dense vegetation around the breeding spots of *G. palpalis* along 10 miles of a Gambaga river was cut, piled and burned. A team of pupa-boys was attached to each clearing gang. At first the pupa-teams preceded the gangs, confirming the breeding spots that had already been marked at the end of 1938. They then continued the pupa survey along the remaining uncleared sections of river, only to find that the breeding flies had shifted there. These new breeding sites were now cleared, but by the time this was finished, the onset of rains made secondary habitat available. In the following dry season it was found that breeding was continuing along the remaining uncleared stretches of river, wherever the fringing vegetation provided suitable shelter. The fly was not finally eradicated until practically all the dense vegetation along the 10 miles of river had been cleared. It was obvious that breeding is possible in many more sites than those which are occupied by choice and which are indicated by pupa surveys. The removal of these favourite sites merely shifts the fly into alternative ones. Consequently the method was abandoned as being no improvement on the clearing technique already in operation, in which experienced headmen and supervisors directed by judgment the removal of all dense shade vegetation along river banks. Nash (1940) had a somewhat similar experience in his "spot" clearing against *G. tachinoides* in Northern Nigeria.

The second and successful attempt at eradication was based on the specific nature of the fly-belt vegetation. Combined tsetse and botanical surveys over a wide variety of inland savanna country had shown, by 1940, that the dry-season habitats of *G. palpalis* and *G. tachinoides* were confined to certain definite plant associations composed of a limited number of species of trees and shrubs. It was found that the different associations are constant for different sets of geological and topographical conditions. Each plant association forms a characteristic and easily recognisable unit, indicating with certainty the actual or potential presence of these species of tsetse. The investigation started with the listing of the plant indicators of the presence of *G. palpalis* and *G. tachinoides* with the object of facilitating survey rather than with that of controlling the flies. The whole of the inland savanna zone, from 8° N. to 11° N., has now been covered, and remarkable uniformity in fly-belt

vegetation has been found. Only 23 species of trees and shrubs have been listed as indicating the presence of one or both of these species of *Glossina*. From 4 to 9, rarely more, of these trees are found together in the associations forming primary fly foci. Other vegetation species are usually present, but are never, by themselves, found harbouring tsetse at all times of the year. The logical conclusion arising from this investigation was that those species of trees and shrubs listed as indicators of the presence of *G. palpalis* and *G. tachinoides* were essential to the formation of dry-season habitats of these flies and that their removal would make the habitats untenable. Such a practical application could be fitted in with the original conception of the tsetse community of a river, taken as a biological unit, being most vulnerable at the points of dry-season concentration, i.e. at the primary foci. If all trees essential to the formation of primary foci were removed throughout an entire river system, the dry-season habitats would become untenable for 4–6 months of the year and the whole fly community would die out. Practical considerations, such as the limitation of the amount of clearing work possible in a single dry season, and the survival of some flies or puparia until the rains made secondary habitats available, might prevent the immediate disappearance of the fly. But a reduced population of flies, deprived of the conditions essential for their dry-season existence, would be unlikely to survive a further dry season. The same reason would prevent the recolonisation of the river system by introduced flies, although small, temporary colonies might be set up during the wet season. If the area of operations were great enough to exclude the possibilities of fly-introduction, either by wet-season spread or by food hosts, the eradication of the tsetse would be complete. The advantages of such a method of tsetse control would be not only the saving in cost and time consequent on the reduced amount of vegetation to be cut, but the fact that clearing would be standardised to an exact technique and would therefore not be merely a matter of judgment. The technique could be easily taught and, what is equally important, rigorously supervised. A further advantage which developed later was the possibility of attaining permanence through the complete eradication of the fly-belt trees.

This principle of tsetse eradication, working to the specific nature of the flies' dry-season habitats, was tried out in Lawra district. The result was spectacular. The dense communities of *G. palpalis* and *G. tachinoides* disappeared immediately on the completion of clearing and, although a few introduced flies were caught in the area during the following three years, not even the temporary establishment of colonies during the wet season took place.

The Significance of the Fly-Belt Vegetation.

For the sake of convenience those species of trees and shrubs which were found to be indicators of the presence of *G. palpalis* and *G. tachinoides*, and the removal of which results in the disappearance of these flies, will be referred to as " essential fly-belt trees ". They are essential to the existence of fly-belts in that they make possible the persistence of these tsetses throughout the year. Wet-season habitats might, broadly speaking, be considered as " fly-belt ". They have a characteristic flora which is less defined and less restricted in composition than that of dry-season habitats. In the absence of adjacent primary foci, however, wet-season habitats would not become fly-belts. The term " essential fly-belt tree " can therefore be restricted to the species essential to dry-season habitats only. The removal of this specific vegetation as a method of tsetse control will be called " Selective Clearing ". The vegetation of dry-season and wet-season habitats is given in Appendix A.

The significance of the essential fly-belt trees lies in their being communal and of such a habit that plant associations containing one or more species can provide the micro-climate necessary for the survival and reproduction of *G. palpalis* and *G. tachinoides* during the extremely adverse conditions of the northern dry season.

The majority of the trees are broad-leaved evergreens. The few species that are deciduous lose their leaves for a short period only. Roughly, two forms can be distinguished: small, many-stemmed shrubs 5–15 feet in height, rarely up to 20 feet; large trees, 20–40 feet high, with the trunk branching low down and the branches wide-spreading and drooping, forming dense, dome-shaped crowns with the periphery, in isolated trees, almost reaching the ground. The most frequent fly-belt associations consist of both forms in regular zonation along the edges of water-courses, lakes or rivers. The central zone is occupied by the large trees which give a high, dense canopy overhead; the outer zones are occupied by the smaller, bushy forms which give a thick, often impenetrable, lateral protection. This association of the two types forms a dense tunnel-like or cave-like shelter along the edges of water-courses, completely enclosing them if they are narrow. On the larger rivers, such as the Voltas, this band of primary fly-belt may be 20–100 yards in width. This is true evergreen gallery forest. More typically, it is a narrow strip of fringing riverine forest 2–10 yards wide. Higher up the courses of the streams a single narrow zone of only the bushy forms can form dry-season habitat. In such cases the river bed is deep and narrow, in itself affording shade and lateral protection. On flat, open water-courses, which form swamps during the rains, the associations frequently form isolated groves, limited in extent but extremely dense. The presence of surface water throughout the dry season is by no means essential for the formation of a primary habitat, but the water table is invariably high, within two or three feet of the surface.

It must be understood that the plant associations comprising dry-season habitats do not consist solely of essential fly-belt trees, but are usually of fairly mixed composition, including tall deciduous or evergreen trees of an upright habit and a number of deciduous shrubs and bushes. The value of the fly-belt trees is that, because of their form and communal habit, they preserve within the association a suitably cool and moist micro-climate. The trees give lateral and overhead protection from the sun and wind, and transpiration from their ample leaf-surface and evaporation from the soil serve to keep down the temperature and maintain the humidity within the canopy. During the dry season the climatic conditions of open savanna woodland are so severe as to be rapidly fatal to both *G. palpalis* and *G. tachinoides*, and these flies can exist and reproduce only in the suitable micro-climate maintained by the vegetation of the dry-season habitat. Even within this habitat conditions can be very unfavourable in a long dry season. Nash (1936) has shown that at Gadau in Northern Nigeria *G. tachinoides*, within the primary foci, is living very close to the lethal temperatures at the end of the dry season, and survives only by seeking out the coolest spots at ground level during the heat of the day. On these observations (1940) he based his "Partial Clearing Method" for the control of *G. tachinoides* and *G. morsitans*. Buxton and Lewis (1934), working in the same area, had observed the prevalence at the end of the dry season of temperatures and humidities beyond the range tolerated by these tsetses, and had suggested the possibility of killing off large numbers of flies by the removal of undergrowth, thus exposing the flies to the severity of the dry-season climate.

With the prevalence of such adverse climatic conditions in the northern savanna, it is easy to understand that the removal of only the protective, evergreen zones of the fly-belt vegetation will alter the micro-climate sufficiently to prove directly fatal to the tsetse. But in the Gold Coast, where the eradication of the fly has been successful and rapid, the climate is less extreme than it is in Northern Nigeria and, from observations, the fly is not living so close to the fatal limits of temperature and humidity. It is suggested that the directly lethal effect of climate is not the only factor responsible for the disappearance of the fly, though it is probably the major one. Sub-lethal temperatures and humidities, by lowering the longevity and the rate of reproduction (Buxton & Lewis, *loc. cit.*) could have an effect ultimately decisive on the survival of the tsetse communities.

The Vegetation Indicator in Eradicative Clearing.

The removal of all essential fly-belt vegetation over a complete river system has been referred to as " Selective Clearing ". A fuller definition is necessary here. In the first place selective clearing is not a method that can be applied at limited points only, i.e. around water-holes, ferries, etc. On the contrary it will not have such good results as protective clearing if applied over short lengths of river, since it deliberately leaves behind a large amount of vegetation capable of being used by the tsetses for temporary habitats. Selective clearing is the technique employed for the eradication of *G. palpalis* and *G. tachinoides* by making untenable their dry-season habitats over a complete river system, or at least over as much of a river system, working from the head-waters downwards, as will place the region to be protected beyond the range of wet-season invasion by the flies. The full-scale application of the technique of selective clearing constitutes "Eradicative Clearing".

As a practical technique in tsetse eradication, selective clearing utilises a knowledge of the specific vegetation of the flies' dry-season habitat for two ends : (1) to reduce to a minimum the amount of vegetation removed in fly eradication ; (2) to designate a precise standard of clearing which can be rigidly followed over a variety of types of country. The second is a most important point. The greater the area over which an unmodified form of selective clearing is applicable, the greater its value as a means of tsetse control. But the very fact that the essential fly-belt trees provide a suitable micro-climate and do not, as far as is known, have any intrinsic attraction for the species of tsetse concerned, implies that modifications in regard to the species of trees to be removed might be convenient or necessary, e.g. to suit local variations in climate or because of the difference in the physical requirements of the two species of tsetses. An examination of these questions suggests that for the inland savanna zone and for *G. palpalis* and *G. tachinoides* modifications are either unnecessary in practice or are not justified when weighed against the advantages of working to a definite formula, easily laid down and easily enforced. However, as experience is gained, modifications may be introduced which will reduce the amount and the cost of the work.

The area over which selective clearing is applicable is indicated by survey : i.e. it will be the area where certain species of plants and no others are the indicators of the presence in the dry season of *G. palpalis* and *G. tachinoides*. Surveys have shown that the list of essential fly-belt trees given in Appendix A holds good for the whole of the inland savanna forest zone north of the parallel 8° N. Within the Gold Coast area more than 300 streams and rivers, representing all the ecological variations of this vegetation formation, have been visited. Definite plant associations, each consisting of 4–9 species of essential fly-belt trees, have been found occurring consistently throughout the zone, the type of association being influenced by edaphic rather than climatic factors. Visits to the adjoining French territories of Togoland and the Ivory Coast have shown that the same plant associations are characteristic for the waterways throughout these areas of West Africa as far north as the limit of the savanna forest zone (about 13° N.), which is also approximately the northern limit of the *G. palpalis* group of tsetse. It is safe to assume that the unmodified form of selective clearing will be effective for the control of *G. palpalis* and *G. tachinoides* over the whole of the northern territories of the Gold Coast and over the corresponding areas of Togoland and the Ivory Coast as far as the northern limit of the flies.

A remarkable feature shown by the surveys is the uniformity over such a large area of the plant associations forming the flies' dry-season habitats. For example, the same association has been seen on the extreme northern bend of the Black Volta River just within French Sudan, 12° 45′. N., and at 8° N. in northern Ashanti. The annual rainfall of the former locality is below 20 inches and occurs between July and September ; that of the latter is 55 inches and is spread over 7–8 months.

This difference in the length and intensity of the wet season represents the main variation in climate experienced in different parts of the Savanna Forest Zone. The duration and intensity of the rains influences the wet-season behaviour and spread of the flies, whereas the critical time for a tsetse community is during the dry season. At this time the adverse conditions of high temperatures and low humidities prevail throughout the whole of this zone down to the edge of the intermediate forest. The monthly mean relative humidity is constantly below 55 per cent. during six months of the year, and relative humidities of 18 per cent. have been recorded (by an accurate whirling psychrometer) at mid-day in March in the extreme south of this zone. Thus, even at the southern limit of the area, the climate is sufficiently severe during several months of the year to make the survival of tsetses possible in certain restricted environments only. The same climatic factors, with the additional one of the annual bush fires, influence the type of vegetation and restrict the evergreen vegetation to narrow bands along the water-courses. The severe savanna climate has such a restrictive effect on vegetation that it is constantly menacing the Rain Forest itself, causing intrusions of savanna zone vegetation within the forest boundary (Chipp, 1922). The microclimate held by the fringing forest in the savanna zone ensures the survival of the tsetse during the critical period of the dry season, and as long as this microclimate is preserved, it makes little difference to the question of absolute survival whether the fly has to endure 8–9 months of restricted habitat, as in the extreme north of its range, or only four months, as in the extreme south. Selective clearing will kill off the tsetse in the north with a much bigger margin of time than in the south, but the method required for eradication will be precisely the same.

Up to this point *G. palpalis* and *G. tachinoides* have been considered together, and the fact that they have different ranges of climatic requirements has been ignored. Relative humidities of 60 per cent. and over, at which the survival and reproduction of *G. tachinoides* are impossible, are well tolerated by *G. palpalis*, which, however, cannot exist at the high temperatures and low humidities tolerated by *G. tachinoides*. It might be expected that the vegetational requirements of the two species would be different, and that the removal of each species would necessitate a different degree of clearing. In practice the need for discrimination against either species alone can be ruled out for two reasons: (1) Both species of tsetse are significant vectors of sleeping sickness, and both species are frequently present in areas where the disease is serious. Therefore discrimination is not a practical policy; a method that will control both is required. (2) Analysis of the data collected in tsetse and vegetation surveys shows that not one of the 23 species of essential fly-belt trees is peculiar to either *G. palpalis* or *G. tachinoides* alone, i.e. every one is a potential indicator of both tsetses. Therefore discrimination against one or other species is impossible.

The list of essential fly-belt trees in Appendix A can thus be followed without modification for the eradication of *G. palpalis* and *G. tachinoides* in the inland savanna zone. It must be pointed out that this does not mean that 23 species of trees and shrubs are always having to be cut down to get rid of the flies. Rarely more than five or six occur together in any plant association, and certain of the species are peculiar to certain habitats and are not found elsewhere. It is possible to get rid of the flies without the removal of every single tree of all the species listed, and this has been done in some places where it was found convenient. But such discrimination needs expert judgment, and it also interferes with a method of permanent eradication which will be described below.

So far selective clearing has been referred to as applicable to the two species of tsetse in the inland savanna forest zone only. This is because the list of essential fly-belt trees has been compiled for these species of fly in this particular area. There is no reason why this method of eradicative clearing should not be applied more

widely and to other species of *Glossina* provided that the principles are followed. Large areas in Tanganyika have been reclaimed from *G. swynnertoni* and *G. pallidipes* by an essentially similar approach to the problem (Napier Bax, 1943). It will certainly be possible to tackle the problem of *G. palpalis* in the coastal savanna zone of the Gold Coast by a modified method of selective clearing. The main difference between this zone and that of the inland savanna is that the relative humidity is constantly high in the coastal plains, never falling below a 55 per cent. monthly mean, but there is a pronounced dry season during which high temperatures prevail. It is possible that a different set of plant indicators may be found in coastal savanna. This problem is now being studied by the essential first step of combined botanical and entomological survey.

The Vegetation Indicator in Tsetse Survey.

This aspect is too large to be dealt with fully in the present paper, and it is intended to make it the subject of a separate publication. But as an accurate vegetation survey is the essential preliminary to selective clearing, some general notes will be given here.

It has already been pointed out that every one of the 23 species of essential fly-belt trees is a potential indicator of both *G. palpalis* and *G. tachinoides* in inland savanna forest, despite the slightly different climatic requirements of the two flies. There is a tendency, however, for certain of the plant associations to be specific for one or other of the species, e.g. *Berlinia heudelotiana—Raphia vinifera* associations or pure *Syzygium guineense* associations usually harbour *G. palpalis* only. But this is not absolute. Both species of tsetse have been found at one time or another in every one of the associations recorded. Associations sometimes appear to be peculiar to one species, but this happens usually towards the edge of the geographical range of the species not represented. For example, in the north of the savanna zone *G. tachinoides* alone occurs in certain light fly-belt associations such as *Pterocarpus santalinoides—Vitex chrysocarpa,* whereas *G. palpalis* appears, together with *G. tachinoides*, only in the heavier type of fly-belt such as *Cola laurifolia—Syzygium guineense* or *Ficus congensis*—other spp. In the south of the savanna zone both species of *Glossina* appear in the lighter types of association, *G. palpalis* alone appears in the heavier types. This is a response to regional climatic variations which are reflected in the micro-climate of the habitat. Nevertheless when such regional peculiarities are understood the type of vegetation can be taken as a reliable indication in fly survey.

It must not be expected that isolated specimens or small groups of essential fly-belt trees, which often occur along water-ways, necessarily indicate the presence of tsetses. Only when these trees are in fairly compact communities can they preserve the suitable microclimate during the dry season. The essential fly-belt trees are communal in habit, and their closed associations represent the edaphic climax for the locality. Open associations of occasional fly-belt trees represent a stage in the vegetation succession. For this reason they should not be allowed to remain in the proper application of a long-term eradication programme. From the point of view of survey, occasional fly-belt trees suggest the presence in the neighbourhood of closed associations where tsetses will be located.

Even the closed association of fly-belt trees is not a certain indication of the presence of tsetse if the further essential factor, suitable food hosts, is lacking. *G. tachinoides* is an omnivorous feeder ; no case has come under observation in which this species was absent from a suitable habitat because of the lack of hosts. In the most densely populated areas, where wild mammals and even reptiles are few or absent, *G. tachinoides* can subsist perfectly well on man and domestic stock. In completely uninhabited regions this fly is equally well represented and it feeds on

game and reptiles. *G. palpalis*, on the other hand, exhibits such a marked preference for the blood of man and cattle that it is absent from uninhabited regions, despite the presence of abundant suitable habitat. In thinly inhabited regions this species is restricted in its distribution to the places where a village or a main road or a trade route is in close contact with a river holding suitable vegetation.

With experience, which enables allowance to be made for peculiar local conditions, the recognition of vegetation types can be a most valuable asset in tsetse survey. This was recognised long ago by Swynnerton for the *G. morsitans* group in East Africa. The writer has, for the past seven years, used this method for rapid surveys by car, cycle and foot of *G. palpalis* and *G. tachinoides*. The method is held to be so reliable that it is frequently used as a check against fly surveys which, for reasons such as low activity or local scarcity, have failed to locate tsetse on a brief visit to a river. African personnel in charge of tsetse survey parties have to attain proficiency in their knowledge of the local flora, and fly surveys are always supplemented by the taking of full notes on vegetation.

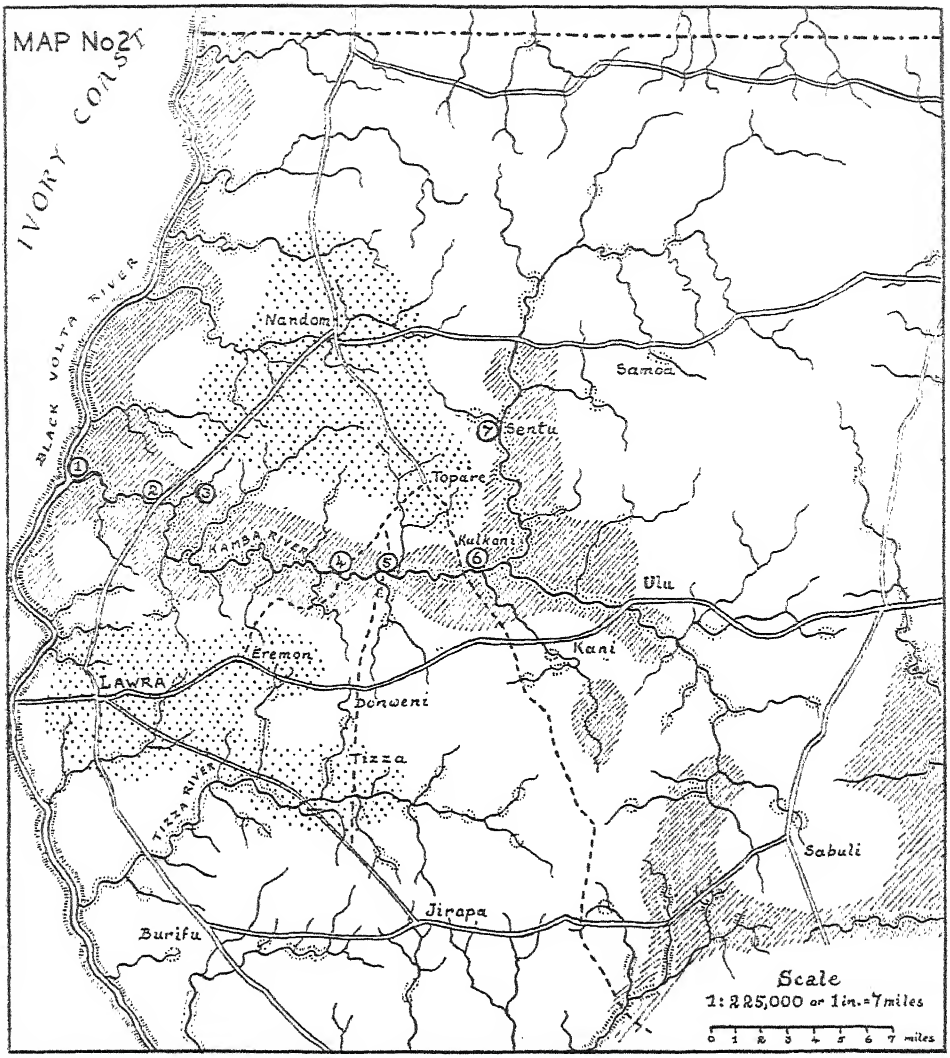
Experimental Proof.

Choice of Area.

The experiment on the eradication of *G. palpalis* and *G. tachinoides* by selective clearing was started on the Kamba River which, with its tributaries, drains 600 square miles (approximately half) of Lawra district. This river flows into the Black Volta eight miles north of Lawra town, the district headquarters. The area was chosen for several reasons. In the first place it lay within one of the most heavily infected regions of sleeping sickness in the Gold Coast, a region which was itself part of the huge pandemic of the upper Volta River basin. The area formed an ideal unit for such an experiment, being of sufficient size and having well-defined, broad watersheds as boundaries. The area was representative of conditions commonly associated with serious trypanosomiasis outbreaks in this part of West Africa, as it had heavily infested fly-belts of *G. palpalis* and *G. tachinoides* along much of the river and contained all but one or two of the primary-focus plant associations that occur in northern savanna. Finally, the river traversed excellent agricultural and pastoral land, a great deal of which had been depopulated through trypanosomiasis. There was the possibility of resettling this land after its reclamation from the tsetse, thereby making full use of the cleared areas, consolidating the gains and relieving a severe population pressure that had developed on the adjoining watersheds. This would demonstrate the wider value of fly eradication in making possible improvements in the local standards of agriculture and animal husbandry.

Survey.

Before the work of clearing could begin, it was essential to have the whole of the river and its tributaries mapped for tsetse and vegetation distribution, on as large a scale as possible, the minimum being 1 : 125,000 ($\frac{1}{2}$ inch to 1 mile). A complete and accurate map of the area of operations is of the utmost importance, because eradication fails if any fly foci, which may have been overlooked on sidestreams or headwaters, are left uncleared. The existing maps for Lawra district were so inaccurate and incomplete, especially as regards water-courses, that topography had to be surveyed and plotted *de novo*. Biological data were recorded and included at the same time. This operation necessitated the training of certain of the African staff in simple surveying with prismatic or floating compass and chain, as well as in field botanical and entomological observation. The more intelligent Africans were quick to learn this type of surveying, and they were eventually capable of making accurate maps. Maps of different parts of the river system were made by separate survey teams, working simultaneously, and these were checked and fitted into a



ERADICATION OF *Glossina palpalis* & *G. tachinoides*.

LAWRA DISTRICT, NORTHERN TERRITORIES OF THE GOLD COAST.

Motor roads

Trade & market routes

Rivers & streams

Fly observation points ①

Dry-season habitat of *G. palpalis* & *G. tachinoides* remaining, May 1945

Dry-season habitat, selective clearing of which effected eradication of the Tsetse

Riverine fringing forest

Groves

Area depopulated by Sleeping Sickness

Area overpopulated (Over 200 per sq. mile)

framework map of the roads made by the writer using prismatic compass and car speedometer readings. All these surveys were plotted on a scale of 1 : 50,000, which is adequate to show the distribution of vegetation types and the detailed configuration of the water-courses. The whole of Lawra district was mapped in this way between 1940 and 1943, and a considerable part of Wa has now been covered. These maps have been checked against recently made Government survey frameworks, and they show a most satisfactory degree of accuracy.

The total length of the Kamba River with all its tributaries was found to be 250 miles. Of this, 105 miles held dry-season habitat vegetation. Fly-belt along the main river consisted of almost continuous evergreen fringing forest with dominant *Cola laurifolia*, *Syzygium guineense*, *Garcinia baikieana* and *Pterocarpus santalinoides*. On some of the lower tributaries a few dense *Berlinia heudelotiana* associations were found, but for the most part the side streams held light fringing forest of mixed evergreen and deciduous trees, with only a small proportion of essential fly-belt trees in the composition of the vegetation around primary foci. On some of the upper branches of the river, extensive flats of open grass savanna were quite free from any fly-belt vegetation, but here and there on such terrain were dense groves of *Ficus congensis*, *Celtis integrifolia*, *Raphia vinifera*, *Syzygium guineense* and other species. These groves were invariably close to villages and were partly artificial in origin, having developed on the banks of ponds and excavated water-holes. Many were sacred groves, and long delays and " palavers " were involved before these could be dealt with.

Clearing.

Throughout the clearing operations the list of fly-belt trees schedules to be cut was strictly adhered to, and all other woody riverine vegetation was left standing. The work was supervised by members of staff who had been engaged on parts of the original investigation since 1937 and had undertaken the preliminary surveys. Before a man was put in charge of clearing gangs he had to pass a test in the recognition of all the common riverine trees. Headmen and some of the regular labourers soon became familiar with the fly-belt vegetation. In the early stages of training, naturally, a certain amount of non-scheduled vegetation was cut, but as headmen and gangs became proficient the selective clearing formula was rigidly followed. As soon as this state of proficiency was attained the cutting of non-scheduled trees was punished by fines, or, if done repeatedly, by the demotion of those responsible. A certain amount of clearing by unpaid, communal labour was done between 1938 and 1940, but this procedure was eventually abandoned as the progress was very much slower than in the case of clearing with paid gangs. The work was frequently inefficient and the labour undisciplined, both of which failings are fatal to operations of such a specialised and exacting nature. Practical notes on the clearing technique are given in Appendix B.

The eradication programme was planned so as eventually to cover the whole area drained by tributaries of the Volta within the Lawra district. The watershed between the Kulpawn and Volta river systems forms a natural boundary to the east, and the Volta River forms the western boundary. After some consideration, it was decided to leave the Volta uncleared. In the first place studies of the epidemiology of the Lawra endemic showed that the majority of the infections were being incurred on tributaries of the Volta and comparatively few on the main river. There are at present no settlements on the banks of the Volta, and those near the river are invariably situated on side streams. The side streams are usually fly-infested, and it is here that there is intimate contact between the tsetse and man and stock. The eradication of the fly from all of those streams might make it unnecessary to undertake any control measures on the Volta itself, where eradication would be difficult and would involve more expense than the situation seemed to justify.

Selective clearing on a large scale was started in December, 1940, and by March, 1945, the greater part, 1,050 square miles, of Lawra district had been dealt with. The work was carried out in three blocks of country, each comprising a natural area bounded by watersheds : (1) the Kamba area, 600 square miles in extent, with 105 miles of clearing finished in 1942 ; (2) South Lawra, 250 square miles, with 48 miles of clearing finished by 1944 ; (3) North-west Lawra, 200 square miles, with 23 miles of clearing finished in 1945. Thus altogether 176 miles of river and stream were cleared, giving an average of 18 miles of primary fly-focus to be cleared per 100 square miles of country. Surveys indicate that this average is fairly typical for the greater part of inland savanna country in this region. Under special conditions, such as hilly sandstone country intersected by numerous small streams, or in the extreme south towards the forest zone, a greater length of primary focus is found per unit area.

Effect on Glossina.

The initial status of *G. palpalis* and *G. tachinoides* on the Kamba River was determined by surveys made in 1937 and 1938 and supplemented by periods of continuous observation (4–16 months) at certain points. *G. tachinoides* was present all along the course of the main river with a remarkably uniform distribution, catches (standardised to 20 flyboy-days per month) varying from 5,600 to 6,800 flies per year. On the upper branches of the river lower densities of flies, from 1,600 to 4,000, were recorded. The distribution of *G. palpalis* was not at all uniform, the fly being absent from the parts of the river lying in uninhabited country but present in varying concentrations wherever there was a constant supply of humans and cattle for food. At the regular observation points the catches varied from 500 to 2,000 flies per year.

With the start of fly-eradication measures six places were chosen on the cleared river for routine observations. Five of these had already been under continuous observation. These points are shown on Map 2. In addition a control point was fixed on the uncleared Volta near the junction of the Kamba. In this fly-belt *G. tachinoides* showed the same average annual fly incidence as on the main Kamba River (5,800 per year) ; but *G. palpalis* was not resident, only a few flies reaching this point from its true habitat round a village three miles down the river. The routine observation points were visited by teams of four boys, supervised by a "fly-recorder", for 5–7 days each month. A working day is eight hours. For comparison all catches were subsequently corrected to a standard period of 20 flyboy-days per month. Observations have been maintained continuously for five years, and the results of these are set out in Table VI, the figures being given as quarterly catches. The distance is given of each observation point from the control (Volta River), measured along the course of the Kamba. An average quarterly pre-clearing fly-incidence is given for the points on the cleared river, based on the routine catches made in 1938–40.

The table shows the rapid disappearance as residents of both species of *Glossina* from all but the lowest five miles of river. This was confirmed by thorough inspections of the whole cleared river in 1942 and 1943 by independent teams, which failed to find any breeding flies, even in secondary foci during the wet season, except on the lowest five miles of river and underneath the Kamba bridge itself. Whenever an odd fly was caught during routine observations, the team would make a thorough search of the locality for other specimens and for possible breeding places. No evidence of breeding was found.

The appearance of occasional flies at the observation points has two possible explanations. They could be upstream migrants from the Volta fly-belt, or they could be introduced by man or animals from neighbouring fly-belts outside the Kamba basin. All the points except numbers 3 and 7 and the control were deliberately chosen because they were on a well-frequented trade or market route crossing

TABLE VI.

Incidence of *G. palpalis* and *G. tachinoides* before and after eradicative clearing on the Kamba River. Catches standardised to 60 flyboy-days per quarter.

Observation point.		(1) Volta River (control).		(2) Kamba Bridge.		(3) Panyani Stream.		(4) Topari–Eremon Road.		(5) Topari–Donwini Road.		(6) Kulkani.		(7) Sentu.	
Miles from control point.		0		5½		7		22		24		29		41	
		G. palp.	*G. tach.*	*G. palp.*	*G. tach.*	*G. palp.*	*G. tach.*	*G. palp.*	*G. tach.*	*G. palp.*	*G. tach.*	*G. palp.*	*G. tach.*	*G. palp.*	*G. tach.*
Pre-clearing quarterly average ..				425	1,650			112	1,701	383	1,406	240	1,639	286	403
1941	I			14	1,314†			8	31	8	42	65	2,076†	183	316*
	II	16	1,372	1	13	2	17	2	24	4	59	64	278†	238	621*
	III	6	908	0	29	3	5	0	3	1	3	6	22	437	200*
	IV	0	1,054	0	57	0	1	4	25	1	35	5	94	284	67†
1942	I	2	2,116	1	92	0	7	0	10	2	14	1	36	17	4
	II	3	2,340	4	27	0	10	0	7	0	2	1	3	1	1
	III	16	1,619	0	51	0	1	0	1	0	1	0	1	0	0
	IV	1	1,366	0	15	0	3	3	3	0	3	0	3	0	0
1943	I	3	728	0	1	0	0	1	2	0	1	0	0	0	0
	II	1	1,867	1	5	0	0	0	0	0	0	0	1	0	0
	III	2	713	0	29	0	1	1	0	0	2	1	0	1	0
	IV	0	952	0	17	0	0	0	2	0	0	0	3	0	0
1944	I	2	1,463	0	9	0	0	0	0	0	3	0	0	0	0
	II	0	1,796	0	10	0	0	0	0	0	0	0	18	0	4
	III	3	1,100	0	7	0	2	0	0	0	0	1	0	0	0
	IV	2	1,501	1	4	0	0	1	7	0	0	0	2	0	0
1945	I	3	1,597	2	6	0	0	0	0	0	0	0	0	0	0
	II	22	4,376	0	1	0	0	0	1	0	0	0	5	0	0
	III	6	2,069	2	232	0	19	0	0	0	0	0	0	0	0
	IV	3	890	0	49	0	5	0	1	0	0	0	0	0	0

* = No clearing. † = Clearing incomplete.

the river, such places forming regular feeding grounds and tending to concentrate the fly. As these routes traverse uncleared fly-belt within six or seven miles of their crossing the Kamba, there was a distinct possibility of flies being introduced at points 2, 4, 5 and 6. Points 3 and 7 are isolated from regular traffic.

There are reasons for supposing that wet-season spread from the Volta accounts for the majority of the flies caught at the Kamba Bridge, point 2. In the first place analysis of the catches there from the end of 1942 to the end of 1945 into dry-season (November–April) and wet-season (May–October) catches shows the latter to be ten times as great as the former. The largest catches occur in September and October, at the end of the rains, at the time when the wet-season migration has reached its greatest extent. Again it is noticeable that in 1945 an abnormally high fly incidence at the control point in the second quarter was followed by very high catches at the Kamba Bridge in the third quarter (most of the flies were caught in September), and this was followed by the unusual appearance of a number of *G. tachinoides* on the Panyani side stream in September and October. The gradual spread of the fly is evident. The Panyani stream joins the main river one mile above the bridge, and had been free from flies, except for three isolated specimens, since the end of 1942. This catching point lies off the main road and is therefore not liable to the introduction of flies, as it is off the principal line of fly migration which evidently follows the main river. To get further proof of this upstream migration, two additional fly-observation points were started at the end of 1943. One is on a side stream which joins the main river on the south side, two miles from the Volta. The other point is on the main river above the bridge, nine miles from the Volta. *G. tachinoides* has been found to reach this point in small numbers in the wet season, but none penetrate up the side stream which is much closer to the Volta fly-belt.

On the central Kamba, represented by points 4, 5 and 6, local clearings had been made in 1940 around the road crossings, and fly-belt remaining within a mile or so of points 4 and 5 and within 800 yards of point 6 was not finally cleared and burned until May, 1941. This allowed the colonisation of secondary foci in the 1941 wet season, which accounted for the continued presence of a certain number of flies into the dry season of 1942. They did not survive this dry season, however, and from March, 1942, their disappearance was complete. The occasional tsetse that were caught at these points during the next three years can be accounted for by their introduction from neighbouring uncleared fly-belts for the following reasons: (1) The captures were equally distributed over wet and dry seasons and did not show the wet-season preponderance exhibited by migrating flies. (2) The fly-recorders' notes showed that captures were always made on market days or after the passage of a crowd of traders. (3) After the clearing of adjacent fly-belts these captures ceased. This is conclusive. The fly-belts at Tizza, on the route passing point 5, were cleared by March, 1944. Some groves at Eremon, on the route past point 4, were not cleared until December, 1944. A sacred grove at Kani, on the trade route passing point 6, was first cleared in March, 1944, and had to be re-cleared in March, 1945. This locality is interesting. The Kani sacred grove lies on a branch of the Kamba but, because of fetish considerations, it was not possible to clear it until March, 1944. The cut brushwood was burned in April. A week later the abnormal catch of 18 *G. tachinoides* was made, 14 on one day and 4 the next, all at one spot under some ebony trees at Kulkani. This is five miles from the Kani grove by footpath, seven miles along the course of the river. Immediate search of the neighbouring river failed to reveal any breeding sites or any more flies, and it is concluded that they must all have come out of the Kani grove when it was burned. The flies had been harbouring under the brushwood piles there. Three weeks later four *G. tachinoides* were caught at Sentu, six miles north of Kulkani. No flies of this species has been caught here since the completion of clearing in 1942, and none have subsequently appeared.

The complete disappearance of the tsetse from Sentu, which does not lie on a frequented route, supports the above evidence that the flies caught on the central Kamba were introduced. Similarly on the Panyani stream, where no trade route is involved, the fly disappeared as completely as at Sentu, except for the capture of a few specimens at the end of the rains, when the upstream movement on the main stream is most marked.

In subsequent selective clearing operations on the Tizza river and smaller streams the processes of clearing and burning have been timed to be finished before the end of the dry season, i.e. before there had been sufficient rain to raise the relative humidity and make secondary habitats tenable. The result has been the complete and immediate disappearance of both species of tsetse. The course of events observed at Sentu on the upper Kamba (Observation point 7) has been typically repeated in later fly-eradication work on other rivers.

An interesting and significant point is that once the clearings were well established throughout the Kamba River, by the second quarter of 1942, no secondary wet-season foci were set up by the occasional introduction of flies. It is probable that more flies than were seen and caught by the flyboys did actually reach the central Kamba, but their numbers must have been too small, or the individuals had arrived at too long intervals, for secondary foci to have become established. Such would certainly have been detected had they occurred. The only breeding that took place was on the lowest nine miles of the river, the stretch up which the gradual wet-season extension occurred. Except in 1945 the amount of such breeding was extremely small. The full extent reached by these seasonal migrations was not definitely ascertained. This question is now being studied.

To summarise the results of selective clearing, localities on the main Kamba River, showing (by standardised catches) 5,600–6,800 *G. tachinoides* and 500–2,000 *G. palpalis* per year before clearing, showed 0–7 flies of each species per year during the three years after the completion of clearing ; catches in the control fly-belt during these years were 4,260, 5,860 and 8,932 *G. tachinoides* (*G. palpalis* not represented). The occasional flies that appeared were traced as introductions from neighbouring uncleared fly-belts, 5–7 miles distant. After the clearing of these fly-belts no more flies were caught on the main Kamba River. At a point on the upper reaches of the river, where pre-clearing catches averaged 1,600 *G. tachinoides* and 1,200 *G. palpalis* per year, totals of 4 *G. tachinoides* and 1 *G. palpalis* were caught in the three and a half years following the completion of clearing. This point was beyond the usual range of migration or introduction. A wet-season migration of *G. tachinoides*, reaching its maximum in September–October, brings flies at least nine miles up the Kamba River from the uncleared Volta. Only a few flies reach this distance, but they may extend farther. This migration is aided by breeding in secondary habitats, but all such breeding stops in the dry season. The migration is confined to the main river, very few flies extending up side streams. In the more recent application of selective clearing to neighbouring rivers the work has been timed so that burning can be finished before the onset of the rains. The disappearance of the fly is found to be rapid and complete.

Effect on Sleeping Sickness.

The effect of tsetse eradication on the incidence of sleeping sickness and a comparison of this with the results obtained by protective clearings have been discussed fully in Part II ; it will therefore be sufficient to summarise the results here.

Fly eradication caused a steady and progressive decline in sleeping sickness, the incidence of which, for the whole area served by Lawra Hospital, fell by 90 per cent. between 1938 (before the application of any control measures) and 1944. In the Kamba area, where tsetse were eradicated by 1942, and in the adjacent south Lawra

area, where fly eradication was not complete until the spring of 1944, a 91 per cent. decline was observed over the same period. Figures of hospital admissions for 1945 show that the decline is continuing but, at the time of writing, the full data are not available for analysis into separate areas.

Considering that sleeping sickness is a slow disease, that uncleared fly-belt bounds the area of eradication to the west, east and south and must be traversed sooner or later by quite a large proportion of the population, and also that *G. morsitans* appeared in a part of the area in 1940 and has only just been brought under control, the rate of reduction of the disease has been very rapid and the degree attained most satisfactory.

In the areas of fly eradication there was no interruption in the decline in trypanosomiasis such as was apparent in areas of partial fly control, where the rate of reduction varied from year to year under the influence of other factors.

In contrast to the sequence of events in Lawra district sleeping sickness has increased recently by nearly 50 per cent. in south-west Wa, where no control measures have been applied, and is showing an increase in certain parts of the adjacent French territory despite the repeated mass treatments and local clearings.

It is logical to conclude that the eradication of the vectors will result in the eventual disappearance of trypanosomiasis. The continued appearance of the disease inside the area of control will depend on two factors, the introduction of *Glossina* and the introduction of cases infected outside. Both these possibilities diminish in importance as the area of operations is increased. The Lawra experiment has shown that the introduction of tsetse occurs only in a narrow marginal zone 5–9 miles wide where the area of eradication adjoins uncleared fly-belt. As soon as the area of eradication is large enough to put the main population beyond this marginal zone, the introduction of infected people, in the absence of *Glossina*, ceases to be a danger to public health and the control of the disease is absolute. In practice the small numbers of flies entering the marginal zone lose their significance as vectors with the general lowering of the incidence of trypanosomiasis, and control is established virtually over the whole area of eradication.

Effect on Agricultural Economy.

When the original scheme for the eradication of *G. palpalis* and *G. tachinoides* from the Kamba river system was formulated, these were the only species of tsetse present. At that time the gradual resettlement of the depopulated parts of the river valley was proposed, with the objects of utilising the cleared areas and of relieving pressure in the over-populated parts around Nandom and Lawra. The invasion of the main river valley by *G. morsitans* in 1939, however, gave an added significance and urgency to settlement. It was considered that by attaining a certain density of population in the thinly populated and unpopulated regions a stable and economical control of *G. morsitans* could be established. The reasons for this and the measures for the initial reduction of this tsetse are detailed in the next section.

No sort of compulsion or material inducement was used for bringing about settlement; it was encouraged mainly by propaganda. In addition dams were provided at certain prospective sites, a few pilot farms were made and subsequently handed over to the natives, and a large compound (for fly-boys and headmen) was built near the Kamba bridge, where it was particularly desired to start a new village. Some of the original car tracks to clearings were maintained as roads. The total cost of these measures, between 1943 and 1945, was only £200.

The result, considering the evil reputation acquired by the vicinity of the river, was most encouraging. Since the finish of the work in 1942, approximately 1,000 people have settled on land adjacent to clearings. This success is almost certainly

due to the quality of the agricultural land along the river. Settlement was almost invariably preceded by some trial cultivation. The yields from the Kamba farms were uniformly good, those for the main food crops being 40 per cent. above the average for the district and considerably more above the yields in the over-populated parts. The planting season is a month to six weeks earlier than on the drier hillside sites, and the contrast between the river valley farms and those on the impoverished soils to the north and south, where many of the people from the Kamba had gone, is most striking. This is the final test to which the native farmer responds.

Some of the most successful farms have been made on flat marshland which previously held the densest type of *G. palpalis* fly-belt. These have been reclaimed by a high-mound type of farming, and as there is annual flooding of the ground, which gives it a top-dressing of alluvial soil, such farms are likely to be permanent.

Besides the families already settled others, living in villages three or four miles away, are now farming riverside land, and further settlement will certainly follow.

The effect on animal husbandry has been equally good. Herds of cattle are now grazed along the river in places where they were never taken before clearing. A large proportion of the Nandom cattle are taken out to the Sentu branch of the river each dry season. Following the establishment of control of *G. morsitans* in 1945 cattle are being moved from the vicinity of Lawra and Nandom to the middle Kamba for the grazing and water. Animal trypanosomiasis as shown by the number of clinical cases appearing at a rinderpest immunisation camp, was considerably reduced in 1943 among cattle from Nandom, Kani and Ulu, the principal areas affected by the Kamba clearings. But the disease was still serious in herds from the Tizza and Jiripa areas; by 1945, however, the cattle from these areas showed very few cases of clinical trypanosomiasis.

In 1943 a native administration stock farm was moved from a site near the Kulpawn River, where animals were continually being lost through trypanosomiasis, to a stretch of the Kamba near Ulu, with very beneficial results. The Agricultural Department have recently started a demonstration farm with good herds of working cattle at a locality on the Tizza River where bovine trypanosomiasis was serious in 1943.

Two incidental benefits that have resulted from the clearing are a reduction in the number of predators, lion, leopard and hyaena, because of the removal of their favourite cover in riverine fringing forest, and an increase in the facilities for fishing. Not only does fishing cease to be a dangerous occupation associated with sleeping sickness, but it is likely to become more profitable. The opening up of long stretches of water makes them more accessible to the fisherman, and the additional exposure to sunlight causes an increase in the numbers of phytoplankton, the basic food of fish.

These developments are not on a large or ambitious scale. They have been kept simple so as to be within the present range of experience of the local natives, who have been responsible for carrying them out in an entirely voluntary way, by means of their own local administration. Very little money has been expended on development, and no additional staff have been required. Thus these undertakings are likely to have the stability and permanence of the natives' own institutions. They are, moreover, easily applicable wherever the eradicative method of tsetse control is undertaken. Since selective clearing is based on the river system as the unit for eradication it fits in with land planning and agricultural development on the widest possible scale. The developments on the Kamba River have demonstrated the readiness of the local farmer to avail himself of land freed from tsetse, and they have emphasised the possibility of his attaining a higher standard of agriculture and animal husbandry when such land is made available.

The Control of *Glossina morsitans*.

The appearance of *Glossina morsitans* in the Kamba valley in 1939 introduced a complication not provided for in the original project. The vegetational requirements of *G. morsitans* are very different from those of the *palpalis* group, and selective clearing against the latter leaves untouched the habitat of *G. morsitans*. Suitable habitat for this species occurs along the valleys of the Kamba River and its two main branches as far as Samoa and Sabuli (Map 2), with a break in continuity on the main river south of Topare. The whole of this area had been surveyed for tsetse in 1937 and 1938, and *G. morsitans* was not found anywhere, although the conditions for its presence, suitable habitat and the abundance of food hosts, were noticed. In 1939 small but regular numbers of this species were found on the lower Kamba. It had evidently crossed the Black Volta from the Ivory Coast, where a vast *G. morsitans* fly-belt exists in almost unpopulated country full of game. By 1940 the fly was well established on the lower Kamba and had spread 40 miles upstream. A light focus was located east of Kulkani, and specimens had been caught north of Sentu. This brought a serious threat both to the prospects of settling and developing the Kamba area and to the district as a whole, so immediate steps for control were considered necessary.

Research on *G. morsitans* in the Gold Coast had already shown two facts in its ecology, its preference for the larger ungulates and its absence from country with a population density above 15 per square mile. These facts are inter-related. Although this tsetse will feed on man and cattle, apparently it cannot maintain itself entirely on such hosts or on the smaller mammals. In well-populated country big game is too scarce and too much disturbed to afford the necessary frequency of opportunities for *G. morsitans* to obtain its food.

It was evident that *G. morsitans* had become established in the Kamba valley because of a recent very great increase in the numbers of the larger antelopes there, consequent on depopulation. Control was planned to take place in two stages—a direct attack on the fly by disturbance and reduction of the big game ; consolidation by settlement of the country to a minimum population of 20 per square mile and development by all possible means. Disturbance and reduction of the big game was done mainly by hunting, which was concentrated on the four species, roan antelope, hartebeeste, water-buck and warthog. Supplementary means were the placing of canoes on the Kamba, where the main trade routes crossed it, so as to keep traffic going through the wet season, and the extension of farming into the uninhabited parts of the river valley. Operations were started in 1941 and, because of limited resources, were concentrated during the next two years on breaking up the Kulkani fly focus and checking the spread of the fly up the Samoa and Sabuli branches. The measures taken were completely effective. By the end of 1943 *G. morsitans* had disappeared from the river east of Kulkani, although on the lower Kamba a 14-fold increase in its numbers had taken place since 1940. On the central part of the river, between Topare and the Lawra-Nandom road, control was started in 1943. This resulted in a 70 per cent. reduction of fly incidence in 1944, and by 1945 a 97 per cent. reduction of the peak (1943) fly-incidence had taken place. On the lower Kamba control was not started until 1944, and it resulted in a 92 per cent. fall in fly-incidence by the following year. This remarkably rapid decline was doubtless accelerated by the success attained on the central Kamba, since herds of game, and with them *G. morsitans*, move freely between these two areas.

The stage has now been reached, with *G. morsitans* eradicated from the upper Kamba and at a greatly reduced incidence on the lower river, at which settlement can play the major role in consolidating the gains. A certain amount of settlement and development has already taken place, mainly on the upper reaches of the river, which are now regarded as safe from any encroachment of *G. morsitans*. On the lower reaches, however, there is still some way to go. As this experimental work

has proceeded, the temporary nature of the control of *G. morsitans* by hunting alone has been apparent. The unpopulated country over which the work has been done is ideal game country, with its abundance of water and all-season grazing and browsing. As existing herds of game have been thinned out or driven off, others have been observed to move in. Any relaxation of hunting would certainly be followed by the reappearance of the fly in numbers. There is no doubt that settlement with development is the only stable means for the ultimate control of this species of tsetse, and is at the same time the most successful and, in the long run, the most economical measure.

Permanence in Eradication.

In large-scale tsetse control operations, involving hundreds of miles of clearing, the question of maintaining the clearings free from regrowth of fly-belt vegetation becomes of considerable importance. The method usually followed, an annual slashing back of regrowth, has several disadvantages: (1) it involves recurrent expense; (2) it occupies trained staff who might otherwise be engaged on new clearing; (3) it is liable to be neglected, and as long as roots and stumps of fly-belt trees remain alive their regrowth may be sufficient to harbour tsetse within a year. These disadvantages increase in proportion to the size of the area under control and might eventually set a limit to the amount of country that can be covered by clearings needing annual upkeep. A system whereby maintenance could be put on a long-term rotation would overcome the disadvantages to a large extent. The permanent eradication of fly-belt vegetation would be of great practical importance. It would enable the formulation of a progressive policy of trypanosomiasis control in which the whole of the resources would be engaged in aggressive rather than defensive work. As the land is reclaimed from the tsetse, it could be handed over to the native for development.

Tsetse eradication by selective clearing affords the possibility of permanence. But if this possibility is not realised, the maintenance can be put on a rotation of about ten years. The work of removing the essential fly-belt trees throughout a river system must be thorough, and should proceed from the headwaters and tributaries downwards, the main river being the last to be cleared. This prevents the rapid recolonisation of the clearings by water-borne seeds, uprooted seedlings or viable branches. Upstream colonisation, if it took place, would be slow and therefore easily checked. The natural means of regeneration, by succession to the edaphic climax vegetation, would also be slow, probably a matter of several decades. But the vegetation of the northern savanna is in a state of delicate equilibrium with the environmental factors, principally climate and bush fires. It is possible that once the plant communities of the streams were altered they might never revert to the present climax associations but stay at a sub-climax, insufficient to afford the dry-season habitat for the tsetse. This presupposes that the existing climate is different from that under which the present plant associations developed. There is evidence to indicate that this is so (Sabiad, 1944). There is the gradual encroachment of savanna on the forest, which is causing some concern to forestry authorities (Chipp, *loc. cit.*). There is the lowering of the water-table apparent in many districts of the Northern Territories. And there is a southward extension of fauna belonging to a more northern zone, e.g. the lion, an animal typical of the thornland zone of the Sudan, is now common in southern Gonja where, according to the natives, it was rare fifty years ago. This evidence is certainly supported by the writer's observations. Certain trees peculiar to the evergreen rain forest of south Ashanti have been found on the elevated ground of the Gambaga escarpment (latitude 10° N. and 200 miles within the Savanna Zone), where a rainfall higher than that of the surrounding flat country has preserved an island of vegetation atypical for the latitude. Throughout the northern savanna up to latitude 11° N. the vegetation

of the fringing forest on rivers with permanent water contains certain species typical of rain forest. Examples of these trees have occasionally been encountered in isolated groves standing in quite open cultivated country, in some instances on hill-tops. It was ascertained that fifty to sixty years ago, before the tribe had grown to its present size, the whole country had been covered with dense bush. It seems reasonable to suppose that the higher plant communities found in the savanna zone developed under conditions more favourable, especially with regard to moisture, than those of to-day. In this case the permanent alteration of the fly-belt associations, which represent the climax, should be possible. Such a long-term question will take a number of years to be answered. Meanwhile the possibility of the complete eradication of the majority of the fly-belt associations by burning, stumping and agricultural methods is being demonstrated in Lawra district.

Burning and stumping by trained gangs can eradicate all the higher types of fly-belt within two years of the completion of clearing. The work is rapid and adds only 15 per cent. to the original cost of clearing.

Three species of fly-belt tree, *Garcinia baikieana*, *Vitex chrysocarpa* and *Antidesma venosum*, complicate the problem of rapid and cheap eradication because of the viability of their root systems and their ability to regenerate from root suckers. This means that the stump and, in the case of *Garcinia*, practically the whole root system, has to be dug out. *Vitex* and *Antidesma* are fairly easily dealt with, the removal of the stump and larger roots being sufficient to prevent any further growth. The presence of these species within a fly-belt association slows down the work of eradication (of fly-belt) so that three or four seasons may be required after initial clearing before the last viable roots are detached and removed. The amount of work involved is, however, very light. A gang of 15 men can do 10–20 miles of this stumping a month, in contrast to a mile a month for the original clearing. The addition to the original cost of clearing will be from 25 per cent. to 50 per cent., according to the nature of the vegetation. But, considering the importance of this type of reclamation to future maintenance, the additional expense and trouble is well worth while. In the organisation of large-scale tsetse eradication projects this part of the work has its place as a sequel to the main selective clearing operations.

It should be possible to kill off, by poisoning, those species of tree resistant to burning. No experiments on this problem have been done owing to the impossibility of getting arsenical salts, the only poisons likely to be effective.

The farming of cleared areas is an ideal method of reclamation that will be permanent at least for as long as the people continue to employ it. For this reason a system of stable cultivation is definitely preferable to the shifting cultivation employed in bush farms. This is possible on the flat terrain which supports the dense groves of *Ficus*, *Celtis*, *Syzygium* and *Raphia*, since this land has a high water table and is subject to annual flooding which deposits a top dressing of alluvium. In the Lawra reclamation work the greatest success in the farming of clearings has been realised in the case of this type of grove, 18 of which have, since clearing, been cultivated by natives and now show no sign of regenerating fly-belt. This cultivation could be very nearly permanent, judging by similar stretches of land in some adjacent heavily populated areas, which have been in continuous cultivation for as long as the local people remember.

On river banks farming on a system of contour ridging can be employed to reclaim the fly-belt, check erosion and make possible the production of fresh vegetables during the dry season, a point of great nutritional importance in the Northern Territories. An experimental plot on a cleared stream near Lawra has now been established for six years and is demonstrating the possibilities of contour farming. The crops grown have been chosen for their value in local nutrition. Tomatoes, large and small peppers, various spinaches and pigeon peas (*Cajanus*

cajanus) are grown in the dry season. Bananas and sugar-cane are planted on the bunds to consolidate them. In the wet season an improved strain of swamp rice is grown in the standing water between the bunds and has shown much higher yields than the rice grown by local methods.

The presence of domestic stock in clearings can have a beneficial effect on checking regrowth. In the dry season, cattle and especially goats, browse freely on much of the riverside woody vegetation, a habit which has been observed to be particularly effective in checking the regrowth of *Mimosa*, a shrub most difficult to eradicate.

With the application of such a thorough stumping programme for vegetation control the question of erosion might well arise. This possibility was visualised and, on the completion of clearing, four check points on the river were chosen. From three or four marked trees in each case measurements were made to the river bank and the width of the river and the depth and contour of the bank recorded. Subsequent observations have shown that at none of these points has any abnormal or even appreciable erosion occurred. Erosion occurs naturally on parts of every river in this region, and is usually accompanied by a building up elsewhere. In the places where the densest type of fly-belt vegetation grows the banks are steep with an abrupt contour at the top. Such banks are particularly liable to erosion at bends in the river. The process of stumping rounds the contour of the banks considerably and produces an angle of slope far more stable than existed previously. Besides this, if burning is done before the end of the dry season, a profuse growth of grass springs up on the cleared banks with the early rains, and this consolidates the surface in a most satisfactory way by the time the river is flowing with a strong current, usually three months later. The writer's conclusion, from observation on the Lawra and other clearings, is that the grass cover which develops on cleared and stumped river banks makes a far more effective check against erosion than the original cover of closed fringing forest, which has a very thin ground vegetation. In addition, the grass cover of river banks with its fresh growth throughout the dry season, affords a most valuable addition to local grazing.

In 1943 an experiment was started on one of the cleared Kamba tributaries with the objects of establishing a grass cover for the control of both erosion and regrowth and the provision of good fodder. Of the five species originally tried, three, *Cynodon dactylon*, *Brachyaria mutica* and *Melinis minutiflora*, have established themselves firmly under local conditions and are competing successfully with the coarse, tussocky savanna grasses. They are all valuable fodder grasses and have a low dense habit that makes them good soil binders.

The conclusion is inevitable. The soundest basis for the reclamation of fly-belt will be found in the full utilisation and development of the land. The writer constantly has in mind the picture of the prosperous, well populated parts of the Gold Coast where the people's own activities have excluded the tsetse fly. But much fundamental work remains to be done. There is, for example, the influence of geological formations on vegetation. On some formations, fly-belt vegetation is never established. The question of the permanent eradication of tsetse by the alteration of vegetation associations will not be satisfactorily settled until all the possibilities have been thoroughly investigated.

Discussion.

The Strategy of Trypanosomiasis Control.

Measures against the tsetse fly, the mass treatment of infected persons, the movement of whole populations, these are the tactics of trypanosomiasis control. Each method has its values and its limitations. Some may be better suited than

others to certain sets of conditions. The strategy of trypanosomiasis control lies in the employment of resources to the best advantage, which implies not only the judicious selection and combination of tactical methods but the full appreciation of the possibilities of each one.

In recent widespread campaigns for the control of *Trypanosoma gambiense* sleeping sickness in West Africa, the medical attack on the problem, by mass diagnosis and treatment of the sick in the field, has predominated. By the employment of an extensive personnel of medical men and native assistants very striking results have been obtained. The disease has been reduced to 1/3–1/10 of its former incidence. But eradication has not yet been achieved. It seems to be the generally accepted opinion that mass treatment alone cannot eradicate human trypanosomiasis (Wilcocks, Corson & Sheppard, 1946). Consequently, campaigns of this kind involve a permanent commitment for the maintenance of staff and institutions for dealing with the disease at its reduced level and for preventing, or coping with, subsequent epidemics.

A direct comparison of the results obtainable by the mainly medical and by the entomological methods of control has been possible during the present work. The sleeping sickness endemic involving the north-west corner of the Gold Coast is continuous with that covering a large area of the Ivory Coast. The French started their well-organised sleeping sickness campaign in this territory in 1939, at the same time that work was started in Lawra and Wa districts. Thus identical conditions existed for comparable series of observations on both sides of the border. By the courtesy of the French authorities the writer has been able to pay several visits to their headquarters and to the French territory adjoining the Lawra and Wa districts, and to obtain information as to their methods and results. Since 1939 mobile teams have carried out biannually repeated examinations of the whole populations of the most heavily infected regions in the French territory, with the complete treatment of all infected persons. Simultaneously, clearings were made at all obvious points of man-fly contact, such as ferries and main road crossings over large rivers. But many of the larger fly-belt trees were left in clearings, which consequently were lowered in their effectiveness, and many points of man-fly contact were missed. These measures had resulted in a very substantial reduction of sleeping sickness throughout the whole territory in 1944. Considering the results area by area, however, there is a high degree of variation, from reductions of over 90 per cent. in the Cèrcle of Diébougou (significantly opposite the area of greatest reduction in the Gold Coast) to no reduction at all in sections of the Cèrcles of Gaoua, Batié and Léo. Indeed, in four localities the disease has increased despite the strenuous prosecution of the campaign. Two of these localities, on the Upper Red Volta and south of Batié, are shown in Map 3, the others are in the Lower Ivory Coast and North Togoland. The results obtained by the French campaign of 1944 are shown (as percentage reductions in the incidence of new cases since measures started) on Map 3, which also gives the reduction obtained by the various methods of tsetse control described in this paper.* The most significant feature brought out by this map is the consistency in the relationship of the results to the control measures where entomological means are employed, and the lack of consistency where the emphasis has been on mass treatment. The results of mass treatment can vary from a high degree of control to complete failure. The reasons for this are worth examination.

Mass treatment, as a method for the control of sleeping sickness, is based on the principle of cutting off the supply of parasites from the tsetse and thus, by repeated applications over large areas, of progressively lowering the incidence of the disease. There are several factors militating against the success of mass treatment. The two most important are extrinsic to the method :—

(1) Infected tsetses remain behind to continue the propagation of the disease.

* The French figures quoted were taken from annual reports of the Service Autonome de la Maladie du Sommeil de A.O.F.

(2) As long as the population is in contact with *Glossina*, there exists the danger of the reintroduction of infection by travellers, etc.

Intrinsic to the method there are three possibilities of failure :—

(1) In the location of cases.—Cases may be away from home or may be deliberately hidden through shame or fear, or some members of the community may avoid examination because of social position, etc.

(2) In the diagnosis of cases.– *T. gambiense* infections are not always easily diagnosed ; the number of parasites appearing in a preparation of blood or gland juice is usually small, and under the difficult conditions of field diagnosis a proportion of cases is inevitably missed.

(3) In the sterilisation of the patient's blood.—A certain number of blood-infection relapses occur in patients after treatment and such patients are infective to *Glossina* ; drug-fast strains of trypanosomes can be propagated ; and there seems to be a possibility of drug-resistance in patients.

For the appreciation of their full significance these possibilities must be considered in relation to the circumstances under which the campaigns have to be carried out. A mass-treatment campaign involves the training and employment of several hundred native technicians who have to work for long periods under the difficulties of bush conditions and are dealing with highly superstitious and frequently very primitive people. The resultant leakage of infections past the teams may be greater than is usually suspected.

Altogether, these sources of failure permit a certain residuum of disease, the resistance of which to further reductions by mass treatment will depend largely on the environment. In places where the conditions for the transmission of infection are not favourable, i.e. where the man-fly contact is occasional or localised, the residual infection may not be built up to any extent between the visits of the mass-treatment organisation and a high degree of control may eventually be obtained. But in places where the man-fly contact is extensive and intimate the residual infection may be built up to such a degree between visits that the successive reductions necessary for control are never achieved. Thus the effectiveness of mass-treatment will be dependent on the prevailing entomological conditions and so be liable to considerable variation. This is, indeed, the experience of mass-treatment campaigns, failures being encountered especially in endemic centres of trypanosomiasis where a large proportion of the population is in close contact with *Glossina*. In the words of Médecin Général M. Vaucel, Director of the French Colonial Health Services, after long experience in the Cameroons : "Mais l'oeuvre purement médicale ne sera parachevée que par la transformation agronomique, économique et sociale du pays." (Vaucel, 1941.)

The weaknesses of mass treatment might theoretically be overcome by increasing the frequency of visits, but this would add greatly to the cost, already high, and might raise difficulties such as a resistance of the people to too frequent interference. A more logical improvement is the addition of some form of entomological control. But the additional control must be adequate, otherwise even the combination of methods may be unable to stem a rising epidemic, as, for example, has been the experience in the Ivory Coast. The need for effective tsetse control can be seen from a simplified analysis of the potentials for the propagation of the disease that remain after different methods of control have been applied.

(1) Mass-treatment leaves—

(Cases missed + infected flies) × full vector potential.

(2) Fly reduction leaves—

$$\left(\text{Infected population} + \begin{matrix}\text{reduced number}\\ \text{of infected flies}\end{matrix}\right) \times \text{reduced vector potential.}$$

(3) Fly eradication leaves infected population only.

A combination of (1) and (2) leaves—

$$\text{(Cases missed} + \begin{matrix}\text{reduced number of}\\ \text{infected flies)}\end{matrix} \times \begin{matrix}\text{reduced vector}\\ \text{potential.}\end{matrix}$$

A combination of (1) and (3) leaves cases missed only.

Consideration of this analysis brings the discussion back to the question of strategy. The addition of entomological measures to a mass-treatment campaign will greatly increase the effectiveness of the latter, and the greater the degree of tsetse control the more rapid and complete will be the results of the combined attack. But if tsetse control can be brought to the point of fly-eradication, this measure alone is sufficient to cause the disappearance of sleeping sickness, and the additional measure of mass treatment merely increases the speed of control and has no effect on the end result. This conclusion has already been reached in the discussion of the effects of clearings on sleeping sickness (p. 217).

A comparison of the relative costs of medical and entomological methods of control is difficult to make, yet expense is a question of considerable importance in an extensive campaign. The initial costs of tsetse eradication will be greater than those of a short mass-treatment campaign, but mass treatment has been found to need constant repetition over four to five years to achieve results comparable to those of tsetse eradication, and these results were attainable only under favourable conditions (Map 3). Further, medical measures alone involve a permanent commitment in order to keep infection at its reduced level. The complete elimination of trypanosomiasis by entomological means will, in the long run, be the more economical as well as the more satisfactory solution. The fact that the various methods of entomological control produce results which are largely predictable and are proportional to the expenditure of effort gives them a decided advantage in the planning of strategy (figs. 4 and 5 and Table V).

Up to this point the discussion has been confined to trypanosomiasis in its narrowest aspect, as directly affecting the health of the people. The wider agricultural and economic disturbances following an epidemic and the need for overcoming them by ridding the countryside of tsetse bring irrefutable arguments in favour of entomological control. Tsetse eradication is the only method which can eliminate the disease and correct its sequelae. Mass treatment could be used in an ancillary capacity for humanitarian reasons, but it is not essential for the eventual establishment of control. Selective clearing for the eradication of tsetse is not, however, everywhere applicable. It cannot be applied piecemeal to short sections of rivers or to isolated points of infection. In situations where eradication is impracticable mass treatment will have its greatest value, particularly when used in conjunction with an adequate system of protective clearings. Human trypanosomiasis has been successfully controlled by moving whole populations out of fly-infested areas. A measure such as this should be used only as a last resort when all else fails, since it represents, where the *G. palpalis* group is involved, the abandonment of land with permanent water, which would lead to the constant evasion of regulations by the population. The concentration of people into land deliberately selected and free from tsetse is a different matter. When such action is accompanied by measures for the improvement of health and economic prosperity, as at Anchau in Nigeria, it represents an ideal solution.

The final decisions on the tactics to be followed involve above all an appreciation of the situation as a whole. In West Africa human trypanosomiasis, the more urgent problem, will guide the main plan of strategy. This does not in any way diminish the importance of controlling both human and cattle trypanosomiasis for the full and stable solution of the problem. In the territory under consideration the main areas of heavy infection lie towards the north of the inland savanna zone

(Map 1). The most heavily infected parts are usually surrounded by areas of light infection and a marked linear extension of the disease follows main roads and trade routes southward to the Ashanti forest. Within the forest the position is not yet fully determined, but the disease appears to be fairly general at a low incidence. With such a distribution it is logical to concentrate operations first on the heavily infected areas by tsetse eradication, which should be applied throughout. The localities of lighter infection should be dealt with later. This is not only a counsel of expediency. It is probable that the reduction of infection in the worst areas may have a decided influence on the course of the disease in the peripheral zones. That a considerable transference of infection is taking place is evident from the linear distribution of trypanosomiasis along roads and trade routes. Also, Northern Territory natives, mostly itinerant labourers, form a high proportion of the sleeping sickness patients found in the forest. It is a reasonable deduction that the clearing up of the northern endemic foci is an essential preliminary to the establishment of control on the main roads and in the forest.

When control has been established in the main endemic areas, the position will be clearer for deciding what measures are necessary in the surrounding zones of lower infection. It may be that fly eradication will be uneconomic if these areas are not required for agricultural development, or are thinly populated with infection occurring at isolated centres. A combination of mass treatment and protective clearings might eradicate the disease comparatively quickly. The trade routes, where they lie outside the endemic areas, show a characteristic localisation of infection wherever they cross rivers. This particular situation is outside the scope of selective clearing, but the consistent use of long protective clearings with mass treatment should be sufficient to effect a high degree of control when the transference of infection from the principal areas has ceased.

On the broader aspects of control there is still much investigation to be done. There is, for example, the problem of the forest, as yet imperfectly understood, or the possibility of eradicating the disease by reducing its incidence below the point at which transmission will continue. These and similar problems will be solved only by research in the field involving first and foremost a full appreciation of that complex of factors labelled, so conveniently, epidemiology. The remedies, requiring equal breadth of vision, must be framed from the point of view of the native, not as a patient to be cured and sent home, but as an entity in a harsh environment from which he, and his descendants, have to wrest a living.

Summary.

The investigations were carried out in the Inland Savanna Forest Zone of the Northern Territories of the Gold Coast, the climate of which is characterised by extreme variations in rainfall and relative humidity between the wet and dry seasons.

Glossina palpalis and *G. tachinoides* are widely distributed along the waterways throughout the zone. They come into intimate contact with the human population and are, in consequence, the most important vectors of human and animal trypanosomiasis.

G. morsitans submorsitans occupies unpopulated and thinly populated regions and so, coming more rarely into contact with man and cattle, is a less important vector of trypanosomiasis.

A pandemic of sleeping sickness, with 30,000 square miles of heavily infected country, lies across the upper reaches of the Volta rivers and involves parts of the north of the Gold Coast. In the areas studied high rates of infection (4–7 per cent.) were found associated with serious population declines which have given rise to

secondary evils, the invasion of *G. morsitans* into depopulated parts and the concentration of populations on the watersheds between infected river valleys, with resultant over-farming, erosion and lowering of the standard of living.

The results of two methods of controlling *G. palpalis* and *G. tachinoides* were studied: (1) " Protective Clearings ", aimed at breaking the contact between the tsetse and man or cattle at certain points only; (2) " Eradicative Clearing ", aimed at the complete removal of tsetse throughout an area.

The effects of protective clearings on the fly were as follows: Clearings less than 300 yards in length are considered useless, and may cause an increase in fly-incidence by forming artificial feeding grounds. Clearings of 440 yards can effect up to 70 per cent. reduction in fly-incidence measured over a long period, but for several months of the year show no reduction or may even show an increased incidence. Clearings up to 880 yards long can bring about 60–90 per cent. fly reduction, but at two periods during the year, at the end of the dry season and in the middle of the rains, their effectiveness is considerably lowered by the invasion of hungry flies into the clearings. Clearings over a mile in length exclude all but a few vagrant flies, but even five miles of clearing are traversed by occasional flies.

A study of the effects of various applications of protective clearings on the incidence of sleeping sickness led to the following conclusions. To have any value protective clearings must be made in as many places as possible over a wide area. They effect no general reduction in the disease if applied at a few places only. Small clearings, averaging 400 yards in length, if made consistently over a large area, can effect up to 40 per cent. reduction in sleeping sickness in 4–5 years, after which the disease tends to become stabilised at the lower level. Long clearings, averaging 1,000 yards, almost double the rate and amount of reduction, effecting 70 per cent. reduction in three years, but the tendency for the disease eventually to become stabilised remains. Clearings over a mile in length at each village caused a reduction of 85 per cent. in one area.

Protective clearings alone are considered unlikely to be able to effect complete control in areas of serious endemic sleeping sickness. They do not entirely exclude the fly, and they do not touch all the points where the transmission of infection takes place. Further disadvantages arise from the fact that, to attain maximum fly reduction, all vegetation, including tall trees, should be cut. This is expensive and difficult and may lead to erosion and the silting up of water-holes, thus driving the people back to uncleared parts of the river. Finally, animal trypanosomiasis can never be controlled by localised clearings, therefore improvement in animal husbandry, and consequently in agricultural practice and nutrition cannot be fully realised.

Eradication of *G. palpalis* and *G. tachinoides* is based on the consideration of the tsetse community of a complete river system as a natural biological unit. During the prevalence of the adverse climatic conditions of the dry season, the breeding and survival of tsetses are possible only in certain restricted habitats from which the flies spread extensively along the water courses during the rains. The dry-season habitats are confined to definite plant associations that are characterised by a limited number of species of trees and shrubs. The removal of only these species throughout a river system renders the habitats untenable during 4–6 months of the dry season and results in the disappearance of the whole fly community.

By the method of selective clearing, 1,050 square miles of country in the north-west corner of the Gold Coast were freed from tsetse between December, 1940 and March, 1945. On the main river of this region, the Kamba, which was cleared by 1942, routine catching after clearing showed 1–8 flies per year in places where the pre-clearing averages had been 2,700–7,500 flies per year. After the clearing of some

neighbouring fly-belts, these occasional captures ceased. Wet-season migration from the uncleared Volta, however, brings small numbers of flies 5–9 miles up the lower reaches of the cleared river.

The incidence of sleeping sickness for the Kamba area fell by 92 per cent. between 1938, the year before the start of control measures, and 1944.

Along the Kamba, 160 square miles of land which had become depopulated through trypanosomiasis is being developed voluntarily by the natives, by farming, grazing, etc. Approximately 1,000 people have settled in parts of this area since clearing was finished.

In 1939 *G. morsitans* invaded the depopulated area, and increased greatly in numbers in the following years. The spread was checked, and finally a high degree of control was established by the disturbance of big game and its reduction in numbers. Settlement of the thinly populated country is needed to consolidate this control.

Selective clearing can be followed by the eradication of essential dry-season habitat vegetation which will enable maintenance to be put on a long-term rotation of about ten years. Permanent reclamation is a possibility that is now being studied.

The relative merits of medical and entomological methods of controlling sleeping sickness are discussed. Mass treatment can have great success, but fails to control under difficult conditions, and has not yet been found able to eliminate the disease. The addition of adequate tsetse control increases the effect of mass treatment. Eradication of the fly is capable of eliminating the disease and does not require the addition of mass treatment to bring this about.

The removal of tsetse throughout the river system, as in selective clearing, has the following additional advantages: It makes possible a sound agricultural development based on the possession of good quality livestock; this reflects also on nutrition. It enables the population to live with impunity in the vicinity of permanent water and, by spreading out at a density optimum for their type of agriculture, to avoid concentrations at local clearings or on dry, hilly country away from rivers; thus the possibilities of over-farming and erosion are avoided and the watersheds and headwaters can be reserved for afforestation. By these means, instead of ground being abandoned to the tsetse, the fly is replaced by a healthy agricultural population.

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APPENDIX A.

VEGETATION OF *G. palpalis* AND *G. tachinoides* FLY-BELT IN THE INLAND SAVANNA FOREST ZONE.

Group I.—Essential fly-belt trees, forming dry-season habitat. These species are always removed in Selective Clearing.

Alchornea cordifolia Muell Arg.
Allophylus africanus P. de Beauv.
Antidesma venosum Tul.

Berlinia heudelotiana Baill.
Canthium hispidum Benth.
Celtis integrifolia Lam.
Cola laurifolia Mast.
Combretum acutum Laws.
x *Combretum abbreviatum* Engl.
Cynometra vogelii Hook.
Dialium guineense Willd.
Dissomeria crenata Benth.
Ficus congensis Engl.
Garcinia baikieana Vesque.
x *Mimosa asperata* Linn.
Morelia senegalensis A. Rich.
Pterocarpus santalinoides L'Her.
Raphia vinifera P. Beauv.
Salix ledermannii Seemen.
Sesbania punctata D.C.
Syzygium guineense D.C.
Vernonia amygdalina Del.
Vitex chrysocarpa Planch.

The list does not include lianes and creepers, such as *Paullinia pinnata*, Linn., and *Quisqualis indica*, Linn., which occur in many fly-belt associations and are cleared with them, but which by themselves do not form primary habitat. The shrubs marked x are on the border line. They frequently enter into the composition of dry-season habitat, but in the Kamba clearings they have been allowed to regrow after initial cutting, and although much of this regrowth is within the range of wet-season migration, it has failed to harbour flies during the dry season.

Group II.—Species which, with or without trees belonging to Group I, commonly form wet-season habitat but are not essential to the formation of dry-season habitat. These species are never cut in Selective Clearing, but may be cut in Protective Clearing.

Anogeissus leiocarpus Guill. & Perr.
Bambusa sp.
Carissa edulis Vahl.
Cassia sieberiana D.C.
Chrysophyllum obovatum Bank.
Combretum micranthum G. Don.
Cola cordifolia R. Br.
Cordia myxa Linn.
Balanites aegyptiaca Del.
Dichrostachys glomerata Hutch. & J. M. Dalz.
Diospyros mespiliformis Hochst.
Fagara xanthoxyloides Lam.
Ficus spp.
Kigelia aethiopica Sprague.
Landolphia owariensis P. de Beauv.
Malacantha alnifolia Pierre.
Mitragyna inermis O. Kuntze.
Oncoba spinosa Forsk.
Sarcocephalus esculentus Afzelius.
Tamarindus indica Linn.
Uapaca guineensis Muell. Arg.
Vangueriopsis leucodermis Hutch. & J. M. Dalz.

APPENDIX B.

Notes on Selective Clearing Technique.

Operations must be planned with accurate large-scale maps showing the distribution of the dry-season habitat, and should always proceed from headwaters down stream. In this procedure tributaries should be dealt with as they are encountered, and not left to be dealt with after the main river is finished. The work is done in three stages, initial clearing, burning and stumping. Clearing can start in November or December, as soon as the floods have subsided, burning should be finished by the time first rains have fallen, about the end of March, and stumping can then be continued until the end of May. If work is continued too long into the wet season, it will be hindered or spoiled through flooding. During the early part of the wet season experienced men survey the whole length of the clearings and give detailed reports on the regrowth of fly-belt vegetation, on which is based the stumping programme for the following year. It may be necessary to repeat stumping for three years for the complete removal of fly-belt vegetation and the programme as a whole must be planned accordingly.

Gangs for the initial clearing are made up of 30 labourers under one headman, who may be illiterate but must be experienced in the clearing work and be able to recognise essential fly-belt vegetation. Groups of two to four gangs work under a literate supervisor, who has had a thorough training in fly and pupa work and the identification of common riverside trees.

Each gang is supplied with 20 cutlasses, 10 felling axes, 5 mattocks, a 5-ft. cross-cut saw and 2 bow saws, a sledge-hammer and wedges. The number of saws varies according to the type of vegetation. Two 4-gallon tins or buckets per gang, kept filled with water by one labourer, saves endless waste of labourers' time going for drinks to the nearest water. Each group of gangs has a grindstone under the charge of one or two men whose sole job is the sharpening and repair of tools. Work is organised as follows: Four or five cutlass-men precede the axe-men to clear underbush for the latter's freedom of action. Axe-men fell and, with the sawyers, cut the tree-trunks into logs convenient for handling. The remaining cutlass-men deal with small branches and pile the slash. The mattock-men dig small roots and stumps and throw them on the piles. Piles have to be made with great care over every big stump, with small brushwood inside and large logs around and on top, and they must not be disturbed until dry enough for burning.

The work of burning and subsequent stumping is of such importance that gangs are reduced to 10 or 15 men under each headman, and as many as possible should be experienced labourers. Burning must be carefully organised. Carelessness here spoils the whole clearing work since regrowth from imperfectly burned stumps can harbour fly in the following year. Fires have to be heaped up as they burn, and any stumps not completely charred are re-burned with odd brushwood. Stumping follows, a gang of 15 men having 10 mattocks, 5 axes and 5 cutlasses. Certain species, e.g. *Cola, Syzygium, Pterocarpus, Berlinia, Ficus*, can be killed by burning, but *Garcinia, Vitex, Antidesma* and *Raphia* are extremely difficult to eradicate, especially the first three species, which regenerate from root suckers. The whole stumps and root-systems have to be dug out, piled on grass and brushwood, and burned. For this most exacting work, only the most experienced men are employed.

During the initial clearing, car tracks are cut roughly parallel to the river, so as to give easy access to all parts of the clearings. This is a most necessary step for the supervision of the work in progress and the subsequent inspection of clearings, and also to facilitate the supply of tools and food for the gangs, who may frequently be living in camps distant from villages and many miles from motor roads.

APPENDIX C.

Costs.

The cost of selective clearing can be seen from the following analysis of the expenses incurred in the original treatment and clearing campaign in the Kamba River area.

Area	600 square miles
Population	33,000
Total length of river and tributaries	250 miles
Length of river with dry-season habitat	105 miles

1. Double survey and mass-treatment	£1,000
2. Clearing for eradication of *G. palpalis* and *G. tachinoides*	1,840
3. Eradication of fly-belt vegetation	600
4. Development	200
5. Control of *G. morsitans*	60
6. Overheads (lorry, cycles, equipment, upkeep and transport)	760
	£4,460

These expenses were incurred mainly in 1941 and 1942, when costs were considerably lower than to-day. Thus items 2 and 3 cover labour at 6*d.* a day, headmen at 30*s.* a month, and supervisors at £3 a month.

At these rates the cost of the initial clearing and burning for the eradication of the fly works out at £17 11*s.* 0*d.* per mile of river treated, or £3 1*s.* 4*d.* per square mile of country.

If the work is taken to the point of eradicating the fly-belt vegetation (which means that subsequent maintenance is very light), the cost is £23 5*s.* 0*d.* per mile of river, or £4 1*s.* 4*d.* per square mile of country.

Overhead expenses add approximately one-seventh to the above costs.

In subsequent work the average rate of initial clearing has remained substantially the same. In terms of man-power a gang of 30 men can average 1½ miles of clearing a month, i.e. 600 man-days of work per mile, or approximately 100 man-days per square mile of territiory freed from tsetse.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 1. Typical dry-season habitat of *G. palpalis* and *G. tachinoides* on central Kamba. Association of *Garcinia*, *Pterocarpus*, *Syzygium* and other spp.

Fig. 2. The same as Fig. 1 after clearing. *Mimosa asperata* has been allowed to regrow but repeated searches by fly-boys revealed no dry-season breeding.

Fig. 3. A reach of the lower Kamba after clearing. Most of the river-bank vegetation had to be removed, but *Diospyros*, *Isoberlinia*, *Mitragyna*, etc., were left.

Fig. 4. A side stream of the lower Kamba with *Acacia* spp., *Lannea* spp., *Bauhinia*, etc., remaining. Even in the wet season tsetse did not appear here.

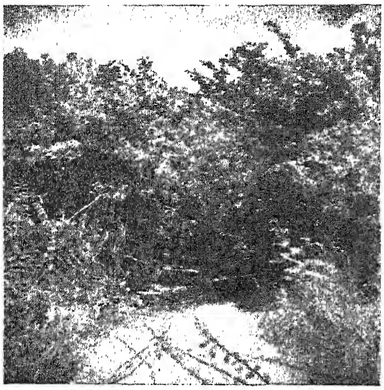

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 1. Closed association of evergreen fringing forest completely enclosing bed of a stream, forming typical dry-season habitat of *G. palpalis* and *G. tachinoides*.

Fig. 2. Fly-free stream with open association of *Ficus gnaphalocarpa*, *Anogeissus leiocarpus*, etc., which could form temporary wet-season habitat.

Fig. 3. Logs and branches piled over stumps immediately after felling. The piles are burned 2-3 months later, when completely dry.

STUDIES ON WHEAT BULB FLY, (*LEPTOHYLEMYIA COARCTATA*, FALL.)

I. BIOLOGY.

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The wheat bulb fly (*Leptohylemyia coarctata*, Fall.) has been causing failures and poor crops of wheat and rye for a number of years in many parts of Yorkshire. Broadly speaking, these attacks fall into two types, one on light sandy soil after second early or main crop potatoes, and the other on very heavy soil after fallows. The first type occurs commonly for many miles around Selby, but it has been a perennial problem well known to this department in the parish of South Duffield a few miles to the east of Selby. Although the soil is unsuited to wheat, a satisfactory crop can be grown, provided the fly does not cause serious damage, after potatoes which have followed a ley. Rye was only slightly less affected than wheat, and it was not convenient to replace them by other cereals. Accordingly, at the suggestion of the Advisory Entomologist, Mr. H. W. Thompson, a study of the biology of the fly under local conditions was commenced in 1943. In 1944 attacks were much more serious and general and afforded an opportunity of extending the work and comparing observations in widely differing localities. It was then found that other districts were also centres of perennial attack resulting in reduced yields and sometimes failures. Damage after potatoes similar to that at South Duffield occurred on the Lincolnshire border at Dirtness Bridge Farm and surrounding farms on black sand. Attack after bare fallows was reported from the parish of Sunk Island in Holderness. In the surrounding areas where fallowing was not necessary, wheat bulb fly was unknown. Other attacks occurred near Stokesley in the North Riding and at West Hardwick in the West Riding. In such areas serious damage was unknown after potatoes though a small percentage of the crop was attacked. The distribution of the fly, or of the areas where it is a pest, thus itself presents problems of peculiar interest and will form the subject of a separate paper.

The principal general paper dealing with wheat bulb fly in Great Britain is that of Gemmill (1927), on which most popular accounts appear to be based. As during the first season's work the time of egg laying was more limited than that mentioned by Gemmill and earlier than had been generally assumed, it appeared desirable to review the complete life history in Yorkshire. There was also some doubt about the time of hatching of the eggs. In fact Gemmill's observations were confirmed at nearly all points, though much additional information was secured. A tabular summary of other workers' findings appears at the end of this paper.

The Immature Stages.

Eggs.

Mean size (50 specimens): $1 \cdot 299 \pm 0 \cdot 086 \times 0 \cdot 374 \pm 0 \cdot 0024$ mm.

The egg has been described and figured by Morris (1925) (whose figure is the better) and Gemmill (1927). Petherbridge (1921) gives a photograph.

Initial development is very rapid, and the general structure of the young larva can be seen if the chorion is removed by dissection two weeks after laying.

To determine the date of hatching, eggs obtained from the field, and from flies kept in captivity in 1943, were kept outside on a north window sill in soil contained in small crock dishes sunk in a large box of soil. Other eggs were placed just below the surface of the soil in small flower pots, in which wheat had been sown, and

others in pots for an experiment described later. These pots were all kept in a slightly warmed glass-house. On 15 January a well-developed larva was found in a wheat plant in the glass-house and from then on further larvae were found in increasing numbers. Certain of the larvae were so large that they must have hatched out some time before the appearance of typical symptoms on the plant.

A few eggs on the window sill had been kept under regular observation, but none hatched until 27 January. As it seemed likely that hatching was general, the eggs were removed from the other pots and examined. Those which had not then hatched were transferred to petri dishes on moist filter paper and further hatchings noted daily. The figures are given in Table I. The exit hole in the chorion is very small and can be seen easily only when at a certain angle to the light and examined carefully under the binoculars. Emergence was by the rasping of a small round hole just below the micropyle. When the shell was crushed or damaged, the hole became more obvious and splitting tended to occur, which may be why Morris (1925) described the exit hole as a v-shaped slit.

TABLE I.

Hatching of Eggs, 1944.

Source.	No. hatched by 28–29 January	January.			February.								Total hatch.	No. dead.	Total eggs.
		28	29	30–31	1	2	3	4	5	6–7	8	9			
Field and laboratory	25	2	5	8	0	0	0	0	0	0	0	0	40	67	107
Field ..	110	11	5	3	1	0	2	0	0	0	0	0	132	113	245
Laboratory	40	—	13	11	5	10	4	2	1	0	1	0	87	9	96
Total ..	175	13	23	22	6	10	6	2	1	0	1	0	259	189	448

Out of 259 viable eggs, 175 had hatched by the end of January. A further 84 hatched within the next ten days, so that the peak hatch under these conditions would probably have been a few days before the end of January.

Most of the eggs obtained from the field had been immersed in strong magnesium sulphate solution during the separation process and had also been subjected to some handling, and this may account for the higher proportion of dead ones compared with eggs from flies laying in the laboratory.

In 1945 the same procedure was followed except that one series of eggs was kept inside the laboratory at room temperature. All the eggs were kept outside in soil till late in December, when they were removed and the apparently healthy ones transferred to petri dishes as before. The hatching dates are shown in Table II with the minimum outside air temperature of the previous night in degrees F. The daily mean temperature was only a few degrees higher than the minimum. Both inside and outside eggs commenced to hatch about the same date, 22–24 January. While the minimum temperature remained at 27° F. or below, no eggs hatched outside, although the maximum hatching of the inside eggs occurred during this period, which agrees closely with the estimated peak for 1944. Hatching recommenced in the outside eggs on 31 January after a rapid rise of temperature. It is also interesting to note that after these eggs had been accidentally left inside for 24 hours on 12–13 February, 31 eggs hatched compared with the previous maximum of 13. Apart from this, the peak would appear to have been about 9–13 February. It is also evident that the eggs can withstand severe frosts.

TABLE II.

Hatching of Eggs, 1945.

Date.	January.															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Inside ..	0	0	0	0	0	0	0	0	5	7	1	1	3	2	0	1
Outside ..	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	2
Min. temp. ..	38	40	42	31	26	—	27	21	16	16	22	21	21	25	27	44

Date.	February.																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Inside	2	1	4	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
Outside	8	2	5	10	9	4	12	5	13	13	2	2	31*	7	7	3	3	6
Min. temp.	40	39	31	—	41	42	44	41	41	38	30	31	36	43	42	34	40	—

Date.	February.										March.					Total hatch.	Total dead.	Total eggs.
	19	20	21	22	23	24	25	26	27	28	1	2	3	4	5			
Inside ..	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	31	30	61
Outside ..	6	6	2	2	1	0	3	0	0	0	0	0	1	0	0	169	67	236
Min. temp. ..	50	44	39	39	40	40	—	41	51	54	45	35	31	—	—			

* Accidentally left inside overnight.

The common practice in Yorkshire, where wheat is sown after potatoes, is to broadcast the seed on the surface and plough or "shell" it in about 2 inches deep. It was thought that deeper ploughing might prevent a number of the larvae from coming to the surface and accordingly in the autumn a small experiment was arranged in which 30 eggs were placed at different depths in each of a series of 12-inch pots and wheat sown in sandy soil. As the plants were attacked they were removed and examined and if necessary replaced by fresh plants. Though there was a reduction in the numbers of larvae recovered from the deeper eggs a surprisingly high proportion found their way through 18 inches of soil. The complete results are given in Table III. There appeared to be some delay in infestation with the deeper eggs, a point noted by Rostrup (1924) in a field experiment designed to test the same point. On the other hand Crüger & Körting (1931) stated that only a

few larvae could rise to the surface when the eggs were buried 20 cm. (8 inches) deep. Recently Petherbridge & Stapley (1945) reported that deep ploughing appeared to reduce attack but the differences were not conclusive.

TABLE III.

Depth of eggs (in.).	Plants showing damage and containing larvae.			Total.
	January.	February.	March.	
$\frac{1}{8}$	6	9	1	16
1	3	13	0	16
4	4	6	0	10
8	1	7	0	8
10	0	3	0	3
14	1	3	2	6
18	1	3	4	8

*Laboratory Observations on the Larvae.**

The mode of entry of the larva has already been described by Gemmill (1927) and his observations were confirmed. The larva almost invariably enters at the basal nodes of the plant (the so-called bulb). The entrance hole is very small and is scarcely visible as a hole, but very soon, within less than 24 hours, the presence of the larva in the bulb causes decomposition and browning which is visible from the outside if the dirty outer sheaths are stripped off. At first it appears only as a slight discolouration or dullness, but even this is rapidly recognised with practice and infested shoots identified.

This technique was very useful for the rapid determination of infested shoots without dissection. In the early stages of the work all plants were dissected but larvae were never found in unmarked plants; similar marks are also caused by the entrance of, or damage by, other species of larvae. The brown mark increases in size until sometimes the whole base of the shoot is rotten. After entrance the grub works spirally upwards for a short distance, rarely observed to be more than 1 inch (but according to Gemmill, 1–3 inches) before settling in the central cylinder. In first instar larvae the head was found to be almost invariably uppermost and usually when the larva was head down it was dead or appeared unhealthy.

The larva at first occurs in the portion of the stem below ground level but in the later stages many occur above ground level and feed on green tissue. On one occasion out of many thousands of plants dissected, a third instar larva was found in the epicotyl (i.e. between the basal nodes and the seed).

As the larvae hatched out, some were transferred in ones or twos to 4-inch or 6-inch pots containing young wheat plants and the progress of these noted at intervals. They were not examined as frequently as intended because it was decided to concentrate on the extensive field attacks then developing (1944) but some information was obtained. The pots were kept in a slightly warmed glasshouse up to the end of March and then taken outside to a sheltered corner which was protected from birds. Some of the plants hardly had time to get established before infestation and they were not growing as strongly as could have been desired. Under these conditions slight stunting or withering of the tip of the central shoot was noticed 5–9 days after placing larvae in the pots. Gemmill puts the figure as low as 3–4 days.

* The three larval instars have been described and figured by Puri (1925).

In another week the damage was more typical and the shoots were turning yellow. After another month (18 March) most of these shoots had withered away to a shrivelled ribbon. The central shoot symptoms vary and may be stunting, wilting, yellowing or browning of the tip or combinations of these depending on the condition of the central shoot at the time of attack.

All the larvae in these pots had left the plants by 29 April and had pupated within 1 inch of the base of the plant and ½ to 1 inch deep. The adults emerged between 20 May and 6 June, some time before those in the field.

Some newly-hatched and older larvae were inserted into lengths of wheat stem about 2–3 inches long which were kept in 3 × 1 inch glass specimen tubes. The stem was held against the side of the tube by a piece of moist filter paper, and several tubes, each containing one stem, were kept in a closed tin. The tins were kept in the glasshouse till the end of February, when they were transferred to the north window sill. This method was found to be very useful as it saved the time and space required for growing plants and the larvae appeared to thrive in spite of being removed for examination and renewal of the stem once or twice a week. Probably because of the early period in the glasshouse, the growth of these larvae was very rapid. Both moults occurred between 10 and 29 February and the larvae were well grown by 10 March. They ceased to feed at the end of March and would not remain in the stem but wandered around the bottom of the tube. A thin layer of soil was put in and the more advanced pupated by 6 April and the remainder by 12 April. The adults emerged between 5 and 12 June, very little earlier than those in the field.

Field Observations on the immature Stages.

Detailed field observations were made in 1944 and to a lesser extent in 1945. They were largely incidental to a study of the development of the attack in relation to plant numbers which is described in another paper. In 1944 at South Duffield in a careful examination of the field selected for study, three larvae were found on 18 January and another three on 26 January. No larvae were found in about a hundred plants taken at random on each occasion. By 14 February about 10 per cent. of the plants showed symptoms of attack. In 1945 no damaged plants were found on 17 January or 2 February. On 14 February about 6 per cent. of the plants were attacked, so that in both years damage started in February and the time agreed with laboratory observations of hatching. During this winter parts of many wheat fields were under water for some time. Although these areas were usually avoided in making counts, it was evident that at least some eggs had survived flooding. In 1944 the proportion of plants attacked and the numbers of larvae per acre increased gradually to a maximum on 10 March, when they remained more or less steady at a figure indicating the total number of larvae which had hatched and successfully infested plants. The gradual increase is due partly to variation in hatching dates and partly to a variable lag between infestation and the occurrence of typical symptoms. Snow prevented counts being made between 14 February and 10 March and it is possible that the peak was reached earlier. Evidently the cold weather at this time hindered development as the proportions of first and second instar larvae were the same on both dates. These proportions are most clearly seen in fig. 1 for both years at South Duffield. In 1944 the first moult occurred during the latter half of February and the first week of March and the second moult during the last week of March and the first week of April. In 1945, despite the slightly later date of hatching, the first moult on an average occurred distinctly earlier than in 1944 and the exceptionally warm March encouraged rapid development, so that by 24 March, 90 per cent. of the larvae were third instar.

TABLE IV.

Percentage of various instars, sizes (in mm.) of larvae from South Duffield (S.D.) and other centres.

Date.	Centre.	1st Instar.				2nd Instar.				3rd Instar.			
		%	Mean.	S.E.	Range.	%	Mean.	S.E.	Range.	%	Mean.	S.E.	Range.
26 January	S.D.	100	—	—	—	0	—	—	—	0	—	—	—
14 February	S.D.	75	—	—	—	25	—	—	—	0	—	—	—
1 March	S.D.	75	1·83	0·07	1·0–2·5	25	2·62	0·06	2·0–3·0	0	—	—	—
10 March	S.D.	38	—	—	—	59	2·77	0·08	1·8–4·2	3	4·24	0·15	3·0–6·3
23 March	S.D.	28	1·00	0·06	1·5–2·5	67	2·93	0·04	2·2–4·8	5	—		—
30 March	Goole	11	—	—	—	70	3·13	0·10	1·9–4·3	19	4·41	0·21	3·5–5·8
4 April	S.D.	7	—	—	—	35	3·23	0·04	2·5–4·4	58	4·57	0·10	3·0–7·0
13 April	Selby	1	—	—	—	3	—	—	—	96	5·13	0·04	4·0–6·5
14 April	Yokefleet	0	—	—	—	0	—	—	—	100	6·13*	0·04	4·5–7·0
17 April	S.D.	1	—	—	—	1	—	—	—	98	6·03*	0·14	3·0–7·0
18 April	W. Hardwick	0	—	—	—	0	—	—	—	100	6·01*	0·13	4·0–7·5

* The mean size of the larvae in this table at the end of the season is somewhat lower than that of a fully-grown one, which would be about 7 mm. Even when this is distended by fixing fluids it would hardly attain the length of 10–11 mm. given by Gemmill.

TABLE V.

Field observations on larvae, 1945.

Date.	Place.	% plants attacked.	Instar %.			% damaged shoots containing larvae.
			1	2	3	
14 February	South Duffield	5–6	97	3	0	100
20 February	South Duffield	20–30 (various plots)	—	—	—	—
28 February	South Duffield	35–50	29	71	0	93
2 March	Sunk Island	54	52	48	0	86
12 March	Dirtness Bridge	48	18	72	10	—
24 March	South Duffield	56 (giant rye and wheat only)	1	9	90	52
25 March	Stokesley	38	0	12	88	45
5 April	South Duffield	—	0	0	100	—
9 April	Sunk Island	—	0	0	100	27
11 April	Dirtness Bridge	—	0	0	100	40

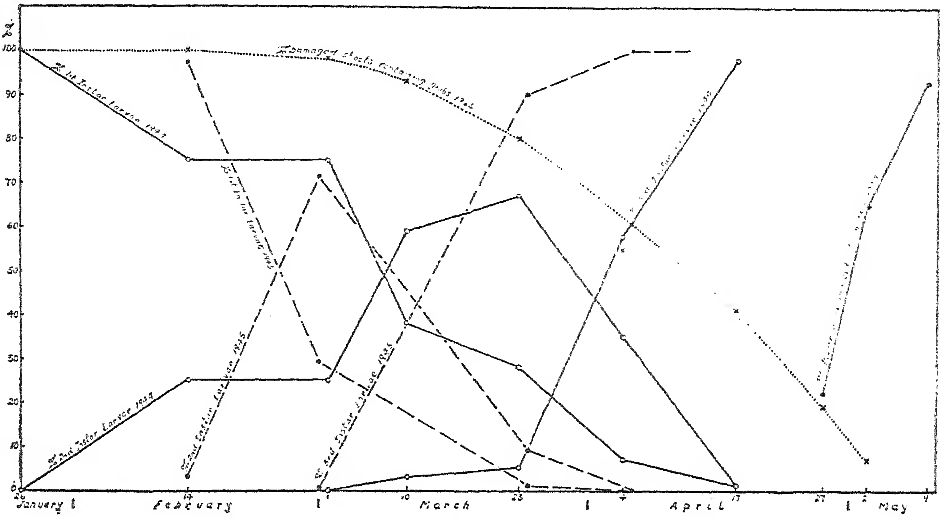

FIG. 1.—Observations on larvae at South Duffield.

The corresponding figures for larvae from other places are interpolated in Tables IV and V to afford a comparison with South Duffield. In 1944 (Table IV) there is little evidence of much variation, though it is probable that had Yokefleet and West Hardwick, both on heavy soil, been visited earlier, the larvae would not have been so advanced as those on the lighter soils. In 1945 (Table V) there is an indication that at Sunk Island and Dirtness Bridge the larvae were slightly less advanced than at South Duffield. Even in one field variations in the rate of development were noted. For example at South Duffield in 1944 a strip of about two acres on the south side of the field had been ploughed 4–5 inches deep and the wheat, Standard Red, drop-drilled and harrowed in. On the remainder of the field the wheat, Little Joss, had been drop-drilled and ploughed in about 2 inches deep. The percentages of the various instars on these two areas are shown in Table VI.

TABLE VI.

Percentage of different instars in two areas.

Date.	Standard Red.			Little Joss.		
	Instar.			Instar.		
	1	2	3	1	2	3
14 February	56·7	43·3	0	82·5	17·5	0
10 March	28·0	66·7	5·3	41·8	56·2	2·0
23 March	20·0	76·7	3·3	31·2	63·3	5·5
4 April	8·6	39·7	51·7	6·4	33·3	60·3

Whether the more rapid development of the larvae on the south strip was due to the different variety of wheat or indirectly to the slightly deeper ploughing, is not known.

Table IV also includes the mean sizes and their standard errors of larvae in different instars. The living larvae were measured by placing them on a scale graduated in 0·1 mm. As they were wriggling and contracting and extending it was rarely possible to measure them with an accuracy greater than 0·5 mm. but it was thought that the mean of a number of such measurements of the larvae in a natural position, i.e. the one they assume in the plant, would be a more useful guide for identification and rate of growth than more exact measurements of fixed larvae. The numbers measured varied but were at least 20 and usually over 50 for each determination.

Fig. 1 also shows the percentage of damaged shoots containing larvae on different dates in 1944. The percentage starts to fall at the beginning of March and then decreases steadily. This is the stage at which the larva has killed one shoot and migrates to another. In most cases it appeared to enter another shoot of the same plant, as usually at this time a slightly damaged shoot would contain a second instar larva and another almost dead shoot on the same plant contained the exuvia of a first instar larva. The presence of an exuvia with its characteristic cephalo-pharyngeal skeleton was a very useful criterion of wheat bulb fly damage after the larva had left the plant.

It appeared from examinations of attacked plants that in the early stages (up to the second instar) a larva migrating from one shoot to another of the same plant descended to the base of the plant and bored into another healthy shoot. Later, third instar larvae were frequently observed to have bored directly from one shoot to an adjacent one when these were held together firmly by the outer sheath. Third instar larvae can also travel some distance in the soil and when placed in boxes have infested plants up to 18 and 12 inches away, the maximum distances tested.

Two or more larvae frequently occur in different shoots of the same plant, but Gemmill never found more than one larva in each shoot. The present writer observed this frequently but in nearly all instances only one of the larvae was alive. At South Duffield in 1944 the frequency decreased with time (*see* Table VII), confirming the idea that when two larvae accidentally infested one shoot, one directly or indirectly killed the other. In 1945 a few shoots were found with both larvae alive and four living first instar larvae occurred in different parts of one shoot. None of these larvae was older than early second instar. Complete records are shown in Table VII. It seems that in the event of a very heavy infestation on a relatively small number of plants, a not insignificant reduction of numbers would take place through this occurrence. Gontcharova (1937) has recorded a similar observation for *Phorbia genitalis*, Schnabl.

TABLE VII.

Occurrence of two larvae in one shoot.

Date.	Locality.	No. of shoots examined containing larvae.	No. of shoots with two larvae.	No. of these shoots with one dead larva.
14 February, 1944	South Duffield	247	7 (2·8%)	6
10 March, 1944	South Duffield	989	7 (0·7%)	7
23 March, 1944	South Duffield	121	1 (0·9%)	1
28 February, 1945	South Duffield	1,083	22 (2·04%)	18
2 March, 1945	Sunk Island	783	8 (1·02%)	4

In 1944 the larvae began to leave the plants towards the end of April and they could then be found in the soil. An increasing proportion of the larvae at this time were distinctly yellowish in colour instead of the previous creamy white. This may

have been due to chemical changes of the fatty layer associated with pupation. The proportion of puparia in the total number of individuals found in the soil increased rapidly during the early part of May and on 9 May nearly all had pupated (*see* fig. 1). In 1945 pupation was much earlier. The larvae were fully grown at South Duffield by 6 April. No puparia and only a few larvae were found in the soil on that date, but by 19 April pupation was practically complete. At Dirtness Bridge the larvae were not quite fully grown on 11 April but pupation was complete by 25 April. At Sunk Island, on a very heavy soil, although most of the larvae had left the plants then, less than half had pupated by 3 May. The remainder pupated sometime between then and 24 May.

Although it is frequently asserted that oats are immune from attack, this statement has apparently been based only on general observations. Opportunity was given for confirming it, in an experiment planned at South Duffield in 1944/45 in conjunction with the East Riding Technical Development Committee. Three varieties of winter oats, Common Rye, Giant Rye, Wheat (Little Joss) and Winter Barley (Pioneer) were sown in the same field after potatoes. The results are shown in Table VIII.

TABLE VIII.

Plants attacked.

Cereal.	% plants attacked (28 February).	No. of larvae—1000's/acre.
Common rye	47	440
Wheat (Little Joss)	36	638
Winter oats (S.147)	3	2
Winter oats (black)	1	0
Winter oats (Picton)	2	2
Giant rye	42	286
Winter barley (pioneer) ..	35	616

Although a very small number of larvae had entered the oats, they were either dead or died shortly afterwards. In one plant a living second instar was found, though this also died soon after being transferred to another oat plant. When larvae were given the choice of various cereals in pots, the oats were invariably the only ones not attacked. The larvae apparently infested the barley normally and survived up to the second instar, but there was strong evidence that relatively few succeeded in reaching maturity.

Wild hosts have not yet been investigated intensively. In arable land larvae havebeen found in *Poa trivialis, P. annua, Agrostis alba* var. *repens* (= *nigra*) and *Agropyron repens*. In the laboratory they have infested *Phleum pratense* and *Lolium perenne*, but none of the finer grasses like fescues or non-creeping bents. Larvae reached the third instar in *Dactylis glomerata* but the plant itself died and they were therefore unable to complete their development.

Pupation and emergence Dates.

The mean sizes and their standard errors of the puparia based on 60 specimens were $5 \cdot 836 \pm 0 \cdot 0142 \times 1 \cdot 925 \pm 0 \cdot 0134$ mm. with a range of $5 \cdot 1 - 6 \cdot 5 \times 1 \cdot 7 - 2 \cdot 1$ mm. Gemmill again gives the somewhat higher figure of 9 mm.

To see whether there were any sexual differences of size or shape, the puparia were separated into four groups, large and small, each sub-divided into more cylindrical ones and more conical ones. No difference in the proportion of the sexes was noted in these groups.

The puparia were kept on the north window sill and the emergence of flies noted daily. In 1944 the peak emergence of males from South Duffield occurred about 13–14 June and of females about 18 June. Gemmill and others have also noted that the males emerged first but Kleine (1915) stated that though females emerged in mid-June in numbers no male was caught before 20 July; this seems so improbable as to suggest a mistake in identification.

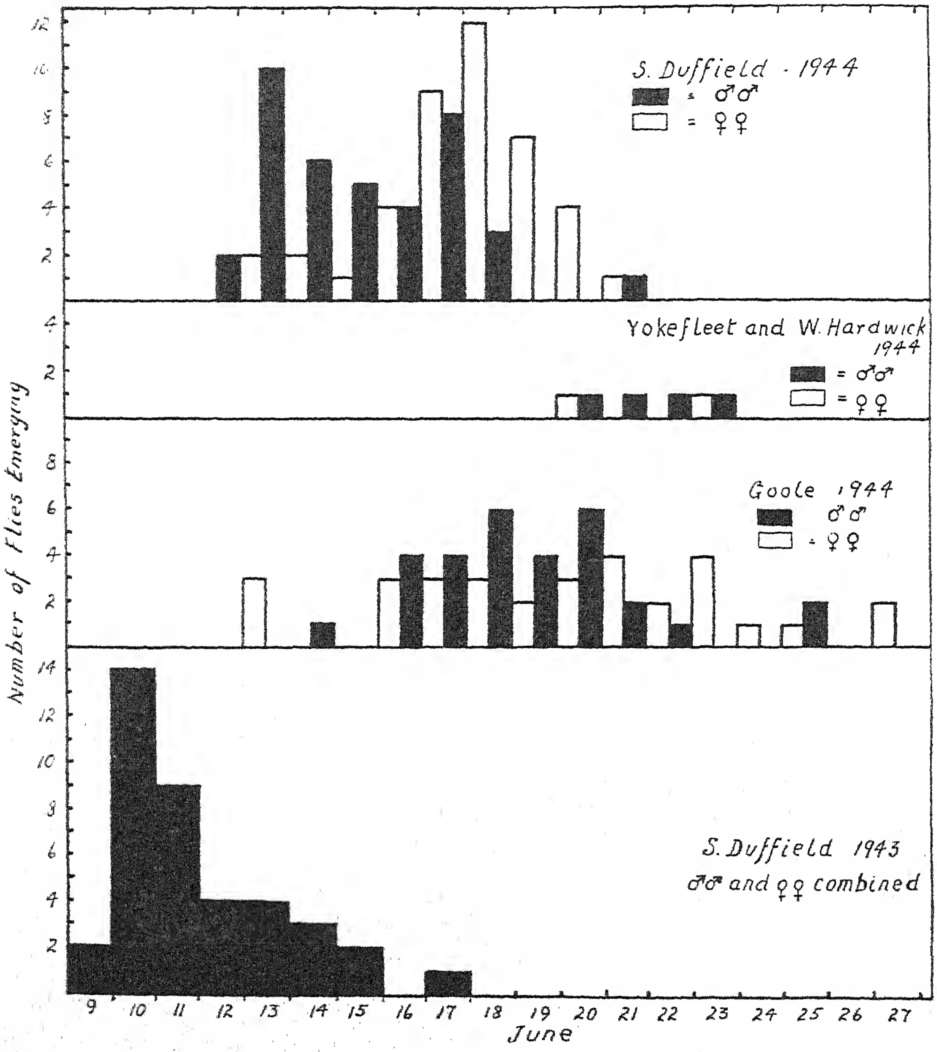

FIG. 2.—Dates of emergence of flies.

The emergence from puparia collected at Goole was slightly later and from Yokefleet and West Hardwick (all three on heavier soils) later still. The flies emerged in the field at about the same dates as those from the same district in the laboratory. A histogram of the laboratory emergence is given in fig. 2, and the 1943 results, which were about a week earlier are also included. In 1945 the earliest emergences were again at South Duffield, reaching a peak in early June. At Dirtness Bridge the flies were a week or so later and at Sunk Island the peak emergence was not till about the third week of June or later.

Biology of the Adults.

Preliminary observations in 1943.

In 1943 all the field observations on the adults were made in and around a field of wheat at South Duffield which had failed in April. The central portion was disked and sown with oats which were poor and later filled up with weeds. A fixed beat was chosen between the remaining wheat and oats and 100 sweeps were taken along it regularly with an entomological sweep net. The catch was examined and tubed after every ten sweeps. To prevent the flies escaping from the net they were stunned by beating the net against the herbage. This procedure was followed throughout June and July in this field and adjacent ones of oats, potatoes and roots. Some flies were observed at the beginning of June and the total catch in the wheat field reached a maximum on 8 June, when the majority of the flies caught were males. The numbers fell rapidly thereafter, due at first to a disappearance of the males. It was thought that these had died off but there was some indication of a relatively high proportion of males in an oat field in the middle of July. There was no indication of large numbers of flies occurring in the potato or root fields though on one occasion just after dawn at the beginning of July, when the dew was still heavy, as many flies were caught in sweeps on the potatoes as on the wheat. The flies had practically disappeared at the end of July and only a few were seen in the early part of August when the corn was cut.

The curve obtained when the number of flies caught was plotted against time was very similar to that shown by Bremer (1929) except that he recorded a few females still existing throughout August.

Observations in 1944.

It was originally intended to take 100 sweeps on the various fields under observation at intervals during the season with the object of relating the numbers to the counts of larvae and puparia and making general observations on the biology of the flies. Very early it appeared, however, that the distribution of the flies in the field in which they emerged was far from uniform. For instance at South Duffield on 16 June shortly after emergence the results of 100 sweeps on the headlands of three sides of the field were 14♂, 1♀; 5♂, 3♀; 2♂, 0♀; and on the other side 199♂, 31♀. Similar occurrences, though not to the same extent, were noted at other places where the flies were abundant and this demanded much more intensive sweeping than was originally intended. To meet this demand the sweeps were carried out by several people and in spite of efforts to standardise the length and rate of each sweep, considerable individual differences in the results were noted. As in 1943, nearly all the flies were brought back to the laboratory for examination, but it was very rarely that mistakes in field identification were made although other species of *Hylemyia* were present.

To obtain as much information as possible without causing too much damage to the crop, 100 sweeps were taken round each edge of each field and occasionally another 100 in the centre. The figures obtained present a number of peculiar features which are discussed below.

An attempt was also made to catch the flies on sticky surfaces. Boards, 12 inches square, were placed in various positions around the field at heights ranging from 1–3 feet from the ground and were covered with fruit tree banding material. The numbers of flies caught were lower than expected but the main difficulty was that unless the boards were examined within two days the flies could not be identified

with any certainty. As time could not be spared for visits more than once a week the idea was abandoned, though theoretically it should give a more reliable index of the numbers and activity of the flies than net sweeps.

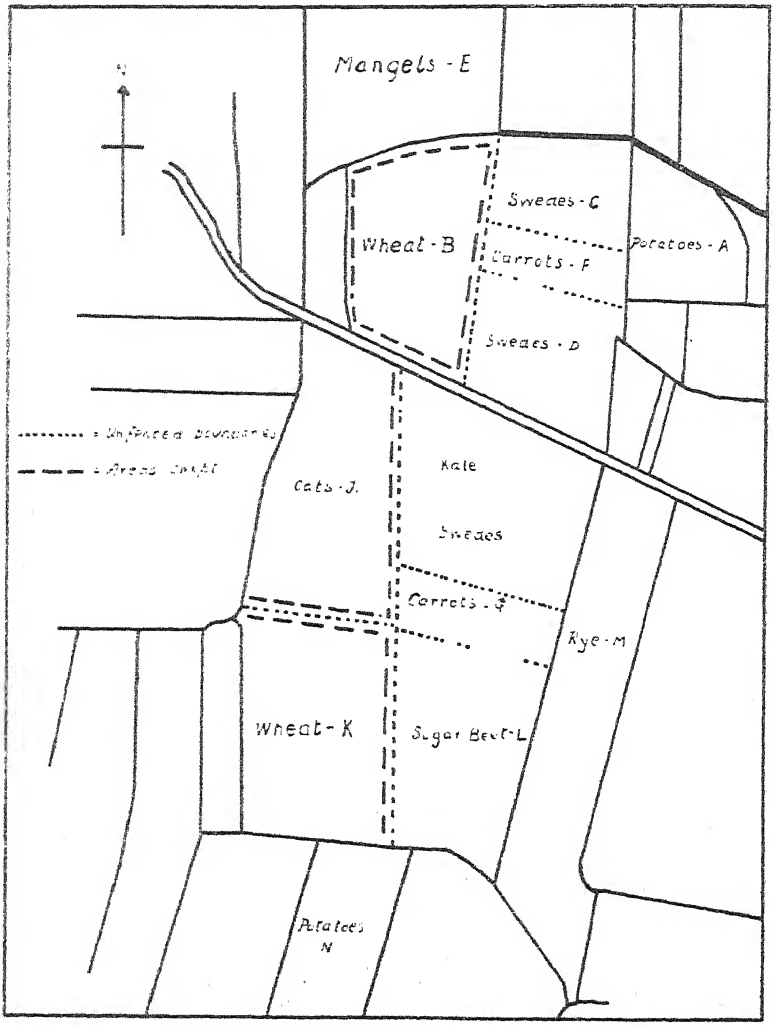

FIG. 3.—Sketch map of fields at South Duffield. Not to any exact scale but represents an area just over half a mile across.

A plan of the area is shown in fig. 3. The wheat fields B and K had both had high larval populations and the only other source of flies in the immediate neighbourhood was the rye field M. The south or road side of B had a low hedge with a fairly wide bank between it and the road. The west side had a tall thick hedge which was continued about half way along the north side after which it became lower and thinner. The east side was open and adjoined a flat of roots. The fields of oats J and wheat K were not separated by a hedge and were also both open on the east side and adjoining root crops. Sweeps in other situations were also made on occasions but they are excluded for the sake of clarity.

TABLE IX.

Numbers of flies caught per 100 sweeps at S. Duffield.

Date.	Time. (B.D.S.T.) 2 hours in advance of G.M.T.	Road verge.		Wheat field B.										Oats field J.				Wheat field K.				Ratio of males to females (1) for most sweeps.	Ratio for certain sweeps only.
				S		W		N		E		Centre.		E		S		E		N			
		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀		
16 June	12.00	—	—	2	0	5	3	14	1	199	31	10	1	—	—	—	—	—	—	—	—	6·4	—
22 June	16.30	—	—	116	31	33	5	67	19	268	132	60	62	—	—	—	—	—	—	—	—	3·9	2·0 (E), 1·0 (centre)
	21.30	—	—	—	—	—	—	—	—	—	—	—	—	13	8	—	—	78	17	—	—	—	—
23 June	9.30–11.30	361	115	68	24	49	22	157	67	208	49	—	—	—	—	—	—	—	—	—	—	2·4	2·0 (E), 3·1 (Road)
29 June	16.30	36	30	—	—	—	—	—	—	—	—	74 62 29 63	67 61 45 82	—	—	—	—	—	—	—	—	1·0	—
	19.30	—	—	—	—	—	—	—	—	101	76	—	—	—	—	—	—	—	—	—	—		
30 June	12.0	35	70	51	69	39	51	32	35	92	105	—	—	44	42	35	54	123	68	63	73	0.9	—
4 July	15.30	—	—	8*	10*	24*	44*	4*	6*	84*	78*	8*	8*	—	—	—	—	—	—	—	—	0·9	—
5 July	15.00	—	—	28*	36*	2*	10*	8*	12*	40*	50*	—	—	—	—	—	—	—	—	—	—		
11 July	15.30	7	29	18	20	17	8	14	25	135	51	—	—	—	—	—	—	—	—	—	—	0·7	2·6(E)
	17.30	—	—	—	—	—	—	—	—	—	—	—	—	520	38	52*	10*	164	10	50*	22*	11·5	—
12 July	7.00	42*	6*	32*	16*	32	12	19	23	140	90	—	—	109	72	—	—	—	—	—	—	1·7	—
21 July	12.00	0*	36*	24*	40*	8*	16*	0*	10*	4*	10*	—	—	—	—	—	—	—	—	—	—	0·3	—
27 July	12.00	—	—	12*	20*	2*	24*	2*	6*	10*	204*	—	—	4*	12*	—	—	8*	22*	—	—	0·3	0·05 (E)
2 Aug.	11.30	—	—	0*	56*	4*	20*	0*	12*	66*	36*	—	—	—	—	—	—	—	—	—	—	0·04	1·8(E)
3 Aug.	14.30	—	—	10*	76*	4*	12*	2*	16*	12*	50*	—	—	6*	32*	0*	14*	18*	76*	—	—	0·2	—
10 Aug.	12.0	—	—	0	24	0	20	0	2	0	80	—	—	0	14	—	—	0	80	0	22	0	—
18 Aug.	11.0	All corn cut and only a few odd flies seen on hedgerows, none caught in stubble or stooks.																					

Some of the data from this area are given in Table IX. The figures are the totals for 100 sweeps from the various situations. Some of the later counts were limited to 50 sweeps to save time but for the sake of comparison these totals have been doubled. They are indicated by an asterisk.

No attempt has been made to analyse the figures statistically. On the whole the numbers for each series of 10 sweeps did not differ greatly and the differences to which attention is drawn in this discussion are so great as to be obviously significant. In the last two columns the sex ratio expressed as the number of males to one female is given. In the first of these columns the figure is based on the largest number of sweeps that appeared to be consistent—usually 300–400. In the other column appear ratios which differ markedly from the "normal" and which are referred to their situations. Some of the sex ratios are based on figures additional to those shown in the table.

It will be seen that, as in 1943, the sex ratio gradually falls from an excess of males to equality about the end of June. This is presumably due to the earlier emergence of the males, but it seems rather more pronounced in the field than in the laboratory. Even up to this stage considerable variations were noted in the sex ratio but possibly the differences are not significant. On 11 July, however, in the middle of the afternoon, the ratio over most of field A was 0·7 : 1, an apparently reasonable figure; two hours later, in a field on the opposite side of the road, the ratio was 11·5 : 1; early next morning it had dropped again to 1·7 : 1, and from then on appeared to fall consistently and reasonably (with again a few exceptions in certain situations) till on 10 August no males were found anywhere.

As mentioned earlier, there was a tendency for unusually high numbers to occur on one side of field B varying from two to ten times the numbers found on the other sides. At the higher limits the denseness of the flies was obvious as one walked by. With three exceptions (5, 21 July, 3 August) the east side of the field was distinctly more densely populated than the others. These and other outstanding numbers have been indicated in italics in the table. On 11 July, for instance, 520 ♂ and 38 ♀ were caught on the east side of field J. It would obviously be interesting to know just how far into the field these belts occurred and early in the season sweeps were taken at various distances from the edge. From these it appeared that the dense population only extended in about one yard. Regular sweeps could not be taken in the corn without damaging it seriously, but four series were taken from east to west on 29 June, and gave numbers similar to "normal" headland sweeps. Similar concentrations were noted elsewhere though not to the same extent. At Goole on 27 July, for example, three sides of the field yielded a total of 17 ♂ and 42 ♀ from 300 sweeps. On the remaining side 10 ♂ and 252 ♀ were caught in 100 sweeps. The sex ratios are respectively 0·3 and 0·04, whereas on an adjoining flat it was 1·5. General sex ratios and maximum numbers of flies for various fields are indicated in Table X.

No other authors appear to have noted similar local distributions, though Kleine (1915) does state that the flies sometimes occur in such numbers in corn that even the farmer becomes alarmed.

This peculiar distribution occurred under all sorts of conditions and without apparent relation to the direction of the wind or sun, though on 5 July, when the wind was in the east, the numbers on this side (which had no hedge or protection) were relatively low. There was no suggestion in the larval counts that higher numbers occurred on that side but counts were not made very close to the edge. Even had it occurred (supposing that strip to have been treated differently in 1943) one would have expected a dispersal sooner or later and such an explanation would not account for the similar numbers on the east side of the oat field J, where no

TABLE X.

Biology of the Adults (1944).

Locality and soil.	June.				July.				August.	
	5–10	11–17	18–24	25–1st	2–8	9–15	16–22	23–29	30–5	6–
South Duffield (sand).	5 No flies 19 ♂ in 100 sweeps	16 Flies abundant S.R. 6·4	22–3 Maximum numbers S.R. 3·9	29–30 Ovaries undeveloped S.R. 2·4–1·0	4–5 S.R. 0·9	11–12 A few eggs ready to be laid, 9/10 fertilised S.R. 0·7	21 Egg laying in progress S.R. 0·3	Egg laying in progress S.R. 0·3	Flies fewer S.R. 0·2	Flies very few and none on 18th
Selby Common (sand)	—	—	22 Flies abundant S.R. 1·2	—	—	—	18 Egg laying in progress, 10/10 fert. S.R. 0·1	—	—	—
Goole Fields (medium warp)	5 No flies	16 A few flies S.R. 4·2	—	—	4 Maximum numbers S.R. 1·5	14 Very few eggs ready to be laid 4/10 fert. S.R. 0·3	—	27 10/10 fertilised S.R. 0·3	—	18 Only one fly seen
Yokefleet (heavy warp)	3 No flies	—	22 A few flies	—	6 Flies more numerous. Ovaries undeveloped	—	21 Flies still numerous, 7/10 fertilised	—	4 Very few flies.	—
Stokesley (clay)	—	—	—	—	2 A few flies S.R. 1·8	—	21 Maximum numbers Ovaries undeveloped 0/10 fert. S.R. 0·5	—	1 Fewer flies Probably some eggs laid, 5/10 fertilised	—
W. Hardwick (clay)	—	—	20 No flies	—	—	10 Maximum numbers, 0/10 fertilised S.R. 3·7	—	24 Fewer flies, 1/10 fertilised S.R. 0·3	—	9 Few flies, 5/6 fertilised No males caught

S.R. = Sex ratio (number of males/1 female). 4/10 fertilised = 4 females out of 10 examined with sperm present in spermathecae.

larvae occurred. Sweeps were rarely made in the potato and root fields as the numbers would hardly have been comparable, but these fields were under observation and the impression gained was that the flies were not much more numerous than in hedgerows or even in grass fields. In the Selby area the flies were common everywhere in June and July and were noted in potato fields which were being inspected for another purpose. Flies were also found in many lanes and fields in districts around South Duffield. All these observations, and the decrease in numbers in the infested field, rather suggest that a random dispersal gradually takes place and that the presence of females in potato fields was more or less accidental, unless they made special visits for oviposition and then dispersed again.

A careful study of this subject would require time and would have many difficulties. Sweeps cannot be taken at the same time in different places and constant sweeping must disturb the flies and directly or indirectly reduce their numbers. The sweeps will not be comparable for different crops and different conditions and can only be done in daylight.

Male aggregations.

Another curious phenomenon, possibly related to those already discussed, was observed on several occasions. On the west side of field B, two large elm trees overhang the corn. On 11 July about 4.30 p.m. (B.D.S.T.), a large number of male flies were seen on the heads of the corn in two separate areas almost exactly below each of the trees. Every few minutes they would rise into the air and settle again almost immediately. Probably this was due to the movement of a few flies which disturbed the others, as the flight could be induced by raising the arm or any other sudden movement, though not by gusts of wind. It was difficult to estimate the numbers but on an average there were 5–6 flies on each of a large number of heads of corn. There were numerous heads without any, or with fewer flies, but there must have been 500–1,000 and probably more under each tree. Towards evening the numbers dropped gradually until one could only say that there were more flies there than in other places. Similar occurrences were noted under every overhanging tree in the corresponding hedge of field K. No aggregations were noticeable in the morning or before about 3 p.m. They were observed on sunny and dull days on some of which there was little difference in the light intensity under the tree and in the open field. Only two or three females were ever noticed in these aggregations and occasional single sweeps into the midst of the flies confirmed that 95–100 per cent. of them were male *Leptohylemyia coarctata.* The testes of the males were examined but did not appear to differ from those of other males. Whether these aggregations had any special significance or were comparable with the large numbers of males taken at about the same time in other parts of the corn is not known. These aggregations were not noticed in any other areas. Balachowsky & Mesnil (1935) state that this species has a preference for woods and for the shelter under trees where it finds protection from the heat of the sun, and they quote a colleague's account of an assembly of flies observed in a wood regularly for a number of years.

Development and maturation of the sex organs.

Visits were paid to the various centres as frequently as possible and 10 males and 10 females dissected and their sex organs examined. The size and condition of the eggs, presence or absence of sperm in the spermathecae and in the testes and vas deferens was noted. These results are summarised week by week in Table X. The object was largely to determine the time of copulation which was observed only twice in the field, once at South Duffield, about 4 p.m. on 11 July, and again near Selby, about 2 p.m. on 19 July. On both occasions contact was only of about a

minute's duration. At South Duffield the pair flew down *in copula*, settled together and then flew away separately. Near Selby the pair copulated and again parted almost immediately. On 12 July, about 5 p.m., a live male brought back from South Duffield was observed attempting to copulate with dead and living females in the same tube, but the latter did not respond.

As can be seen from the table, 9 out of 10 females at South Duffield had been fertilised by 12 July and 10 out of 10 at Selby on 18 July. The other districts were somewhat later, but in all it was about three weeks after the maximum emergence as far as the limited number of observations permit conclusions to be drawn. It was noticeable that sperm were rarely present in the spermathecae before the eggs had reached about half their final size. The thickness of the walls of the spermathecae seemed to differ in some areas, but this point was not studied in detail.

Numbers of eggs laid.

There are 16 ovarioles in each ovary and 32 eggs become mature together and are laid within a week or so. Whether all of the second, or subsequent series of eggs are generally laid is not known, but the maximum number of eggs laid by one fly in the laboratory was 50 and the average of about a dozen females was 22·5. These flies had been caught in the field and some would undoubtedly have already laid some eggs and others died before laying all their eggs. Gemmill suggests that each fly lays about 50 eggs and Hedlund (1907), quoted by Kleine (1918) and Rostrup (1924), states 20–40. The most satisfactory method of keeping the flies for egg-laying was to confine the females singly (or with one male) in a glass cylinder about 7 inches high and 4 inches wide. A small bottle containing flowers of grasses, Compositae, and Umbelliferae, and a small dish of dry soil were also placed under the cylinder and the flies oviposited in the soil. The soil was examined twice a week. There was some evidence that eggs laid after the first 32 were somewhat smaller and had a tendency to shrivel after being laid.

In loose soil the eggs were deposited usually just below, but not infrequently on, the surface in ones or occasionally in groups of two to six. In heavy land which was being fallowed the eggs were observed on medium-sized soil crumbs underlying the larger clods.

Egg laying period.

Rostrup (1924) described an attempt to ascertain this period by covering up certain areas of soil and uncovering them at regular intervals and observing whether wheat sown in the soil was subsequently attacked. To gain additional information the covering material was covered with soil which was also transferred to pots in which wheat was sown. This method, though ingenious, did not give any idea of the peak period of laying and only whether or no some eggs had been laid in a certain period. The present writer therefore preferred to take regular random samples.

In 1943 a few eggs, about 10 per cent. of the final number, had been laid by 1 July. By 15 July between one-third and one-half of the eggs had been laid and all the flies had apparently disappeared at the beginning of August when final egg samples were taken.

In 1944 field A in fig. 3, the nearest flat of potatoes to the main wheat field, was sampled. As only comparative information was required, only the tops of the ridges were sampled, 10 samples, each 6 × 4 inches in area and 1 inch deep, being taken at weekly intervals.

The most important differences are those of the time of oviposition. In many cases this period has been deduced from the occurrence or non-occurrence of wheat failures after certain conditions or cultivations on a known date in the previous summer or on the continued presence of some flies. The apparently few flies found late in the season may lay a disproportionately large number of eggs, but this seems improbable. The number should, however, be determined accurately by soil sampling. There is a variation of two to three weeks between different places in the same season and between different seasons in the same place.

Acknowledgements.

Thanks are due to Messrs. H. W. Thompson and L. R. Johnson for many helpful suggestions and criticisms. Messrs. R. Lawton and G. E. Thomas helped in the routine examination of several thousand plants, of soil for eggs, and made many field observations on the adults. R. Lawton especially has been closely associated with every phase of the work and has put forward many useful ideas. He also translated Rostrup's paper from the Danish. Dr. N. H. E. Gibson also assisted on various occasions, especially in connection with the work on the adults.

Summary.

Laboratory and field observations have been made on the biology of Wheat Bulb Fly in the years 1943–45. The eggs hatch in late January and early February. Severe frosts delay hatching but do not kill the eggs. In a laboratory experiment a high proportion of eggs buried 18 inches below the soil surface, hatched, and the larvae infested plants. Field observations showed that proportions of the eggs also survive prolonged flooding.

The development and habits of the larvae are recorded. It was confirmed that oats are not a suitable host and though a very small number of these plants were infested the larvae did not survive. Occasionally two larvae infest the same shoot and when this happens one larva dies. The larvae leave the plants in April or early May and pupate in the soil. The pupal stage lasts six to seven weeks.

The adults emerge, males first, in June. Copulation occurs about three weeks after emergence and at this time dense aggregations of flies occur. Usually males predominate in these and in certain circumstances all the flies are males. The flies disperse gradually from the field in which they emerged and the females start laying eggs in suitable areas about a month after emergence. In Yorkshire egg laying occurred in July and early August and lasted about a month. Even within the limited area and time of these observations variations up to three weeks were noted in different places and seasons. Lateness was associated with heavy soils.

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ECOLOGICAL AND PHYSIOLOGICAL STUDIES ON *CAPNODIS* SPP. (COL., BUPRESTIDAE) IN PALESTINE.

III. STUDIES ON THE ADULT.

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The present study is based primarily on beetles collected in the field. Although several individuals of *Capnodis carbonaria*, Klug, and *C. tenebrionis*, were reared successfully from egg to maturity, these beetles were as a rule weak and short-lived, and consequently unsatisfactory for the purposes of this investigation.

Over 500 females and many more males, collected in the field, were reared over a period of six years. The specimens of *C. tenebrionis* and *C. carbonaria* came chiefly from almond groves, and other stone fruit orchards, whilst those of *Capnodis cariosa*, Pall., were collected from Pistacia bushes. The female beetles were bred individually, in glass jars covered with cheese-cloth, with one or two males; food, fresh almond twigs, was supplied every other day, or once every three days. The jars were kept throughout the year outdoors, in the shade, unless the experiment called for other conditions.

Pre-oviposition Period.

The adult beetle remains in the cell for some time immediately after maturing until its body has hardened. When the mouth-parts have become sufficiently strong the beetle gnaws a hole in the bark covering the cell and crawls into the open.

Quite a long time elapses between the emergence of the adult and the first egg-laying. Beetles bred from the egg in the laboratory and retained in the thermostat at a constant temperature, died before they began laying. The pre-oviposition period was, therefore, calculated from the laying records of beetles of *C. carbonaria* collected in April and May, 1938–39. Two females, for instance, bred in the room at a temperature fluctuating between 20° and 30° C. (average 24° C.) lived ten weeks before beginning to oviposit. When the beetles were bred outside the period was much shorter. Four *C. carbonaria* beetles, collected in April, 1938, and bred outdoors, were kept in captivity from 30 to 40 days before they began laying. The temperature fluctuated between 12 and 41° C. with an average of 25° C., but the average daily temperature was far above 30° C.

These records indicate that females maturing in the spring or summer may begin laying that same year. When the female, however, matures in the later summer, i.e. late in July or August, the lower temperature of September may be encountered before the end of the pre-oviposition period, and she may lay little, or nothing at all, that year. Such a female will overwinter and begin laying the following spring as soon as the temperature becomes sufficiently high.

Oviposition.

Rate of Oviposition.

Like many other Coleoptera, oviposition is continuous throughout the life of the female although it is not uniform but interrupted by short periods of rest. The length of these periods and the corresponding number of eggs laid depends upon the age of the female and the climatic factors. No general rule can be laid down, nor can a curve be drawn for the oviposition of *Capnodis*, but the rate is increased, as might be expected, at higher temperatures. A few examples are given in the accompanying figures. For instance, the rate of egg-laying of two females of *C. carbonaria* at constant temperatures, namely, one fluctuating between 27–30° C.,

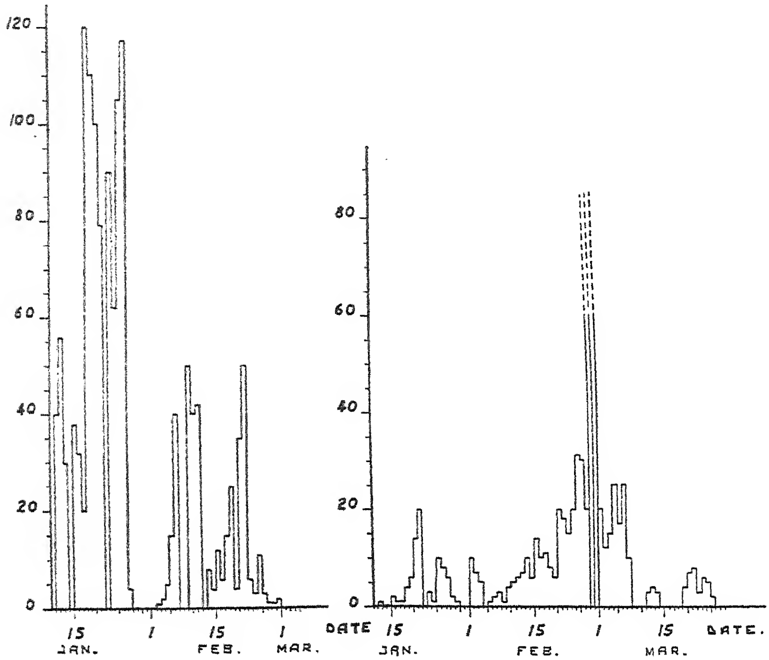

Fig. 1.—Total oviposition of two females of *Capnodis carbonaria* bred in thermostats; one (left) at a temperature of 35–37° C., and the other at a temperature of 27–30° C. (Note.—At the end of February this thermostat was out of order and the temperature went up.)

and the other between 35–37° C., is given in fig. 1. The rate of egg-laying of one individual of *C. tenebrionis* outdoors during the summer of 1937 is given in fig. 2, while in the case of two *C. cariosa*, oviposition records outdoors during the summer of 1939 are given in fig. 3.

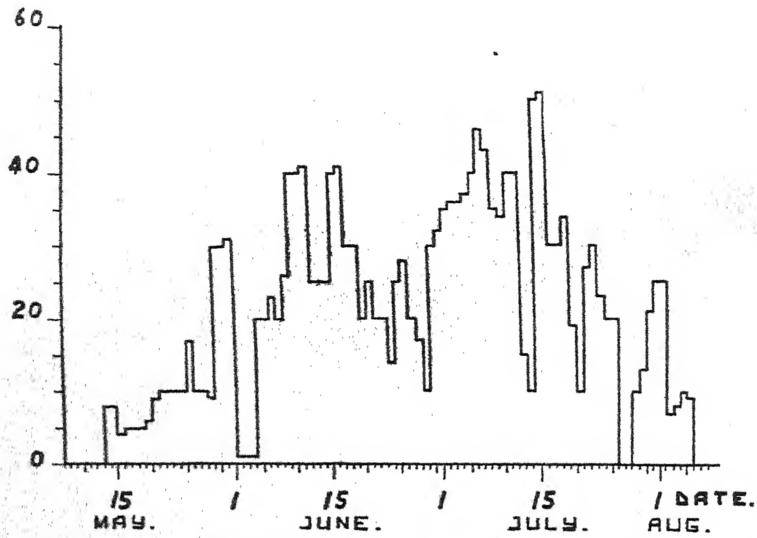

Fig. 2.—Total oviposition of one female of *Capnodis tenebrionis* outdoors.

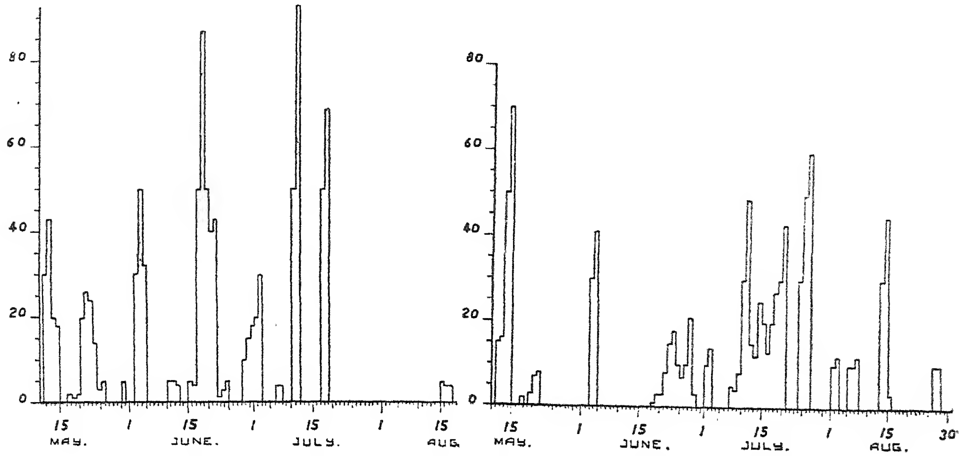

FIG. 3.—Total oviposition of two females of *Capnodis cariosa* outdoors.

Number of Eggs per Female.

The number of eggs laid by one female varies from a few dozen to several hundred. A few examples in which individuals laid many eggs are given in Table I.

TABLE I.

Date of captivity.	Date of death.	Length of life (days).	No. of eggs laid.
	C. carbonaria.		
4.38	18.4.39	353	2,694
4.38	18.4.39	353	2,971
15.5.38	19.12.38	218	652
20.8.38	18.4.39	241	1,776
7.4.38	22.12.38	259	2,559
	C. tenebrionis.		
1.4.38	1.5.39	395	1,696
1.4.38	7.4.39	372	1,264
2.4.38	27.4.39	329	1,428
2.4.38	27.4.39	329	1,234
2.6.38	9.1.39	221	862
	C. cariosa.		
9.5.39	16.5.40	372	928
9.5.39	28.11.39	203	333
9.5.39	26.10.39	170	999

Individuals such as those quoted were rare and as a rule the number of eggs laid was far below these figures. For instance, of 16 females of *C. carbonaria* captured late in the summer of 1939, eight females laid from 50 to 100 eggs, four laid from 100 to 200, two laid over 200, while one laid 327 and one 601 eggs. Of four females of *C. tenebrionis* captured in 1939, one laid 59 eggs, two over 200, while one laid 1,845 eggs. Of four females of *C. cariosa* captured in June, 1937, one laid 138, two laid about 400 each, and one laid 645 eggs. Females which laid less than 50 eggs were disregarded. Such females were quite numerous, as were also those which did not lay at all. For this reason an average number, based on the total number of eggs, divided by the number of females, does not present a true picture.

Threshold of Reproduction.

A high temperature is required for normal oviposition, and the optimum temperature from observations on breeding experiments was found to be in the neighbourhood of 30–34° C. A temperature above this brings about an accelerated abnormal egg-laying, with rapid exhaustion of the female (fig. 1). At a temperature below 30° C. egg-laying is reduced. The different rates of oviposition below and above 30° C. may be judged from the following experiment.

Thirty females of *C. carbonaria*, all captured on the same day and in the same locality, were divided into two lots. One lot of 15 was bred indoors, where the temperature never rose above 30° C., while the other lot of 15 females were bred outdoors, where the daily temperature during the laying period fluctuated between 30–40° C. The females of each lot were bred individually with two males, and egg counts were made every alternate day until death took place. The marked difference between the number of eggs laid at 26–30° C. and at 30–40° C. may be seen from Table II.

Table II.

Difference in total oviposition between females bred indoors and outdoors.

No. of eggs laid by each female during captivity.	Females bred indoors at a temperature below 30° C.	Females bred outdoors at a temperature above 30° C.
0	4	2
1–20	5	2
20–100	3	4
100–1,000	3	5
Above 1,000	0	2

The total number of eggs laid by the females outdoors was 7,165, giving an average of 478 eggs per female. The total number of eggs laid by the 15 females indoors was 1,271, making an average of 85 per female.

An analysis of the egg-laying of the indoor breedings of *C. tenebrionis* and *C. carbonaria* indicated that oviposition took place only when the temperature was above 26° C. and that no eggs were ever laid below this temperature. In order to establish this fact experimentally, ten laying females of *C. tenebrionis* were kept for four months alternately, for periods of a month at a time, outdoors and in a cellar. After four months the egg-laying ceased entirely because of low temperatures and the experiment was discontinued. The maximum temperature outdoors ranged between 34° C. and 42° C., whilst that in the cellar fluctuated between 24–26° C. The results are shown in fig. 4. No oviposition took place when the beetles were in the cellar although a few eggs were laid during the first five-day period, but this can be attributed to the carry-over influence of the higher outdoor temperature. The effect of darkness can be disregarded because on other occasions beetles confined in dark thermostats laid freely when the temperature was suitable.

The egg-laying period of the *Capnodis* spp. is so irregular that no mathematical calculation of this phase was possible, but observations over a period of six summers, in addition to this experiment, afford sufficient evidence that the threshold of reproduction of *C. carbonaria*, as well as of *C. tenebrionis*, is approximately 26° C. With *C. cariosa* it is somewhat lower, as females were ovipositing even at 24° C.

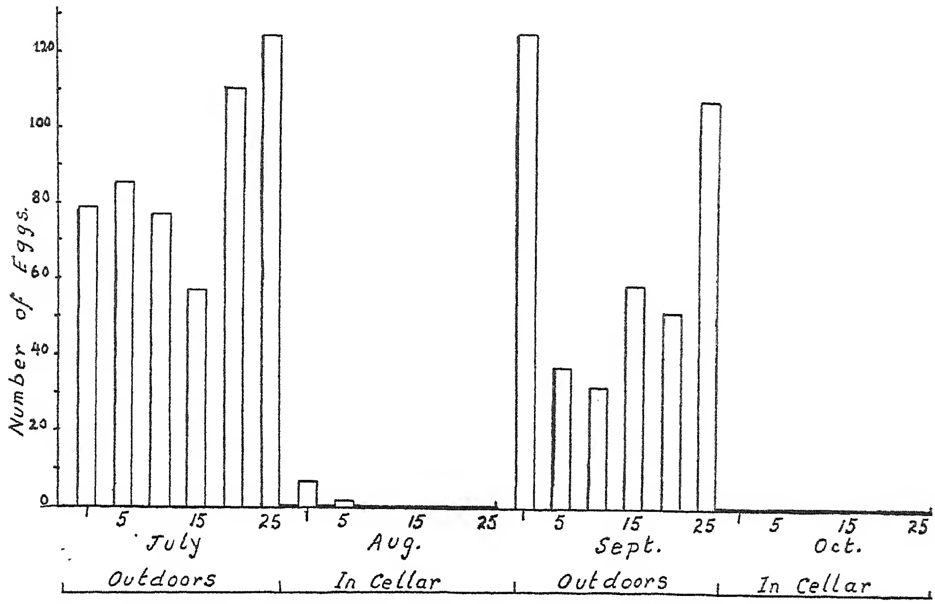

FIG. 4.—Oviposition of ten females of *Capnodis tenebrionis* bred alternately outdoors (day temperature above 30° C.) and in a cellar (temperature 24–26° C.).

Periodicity of Egg Laying.

Having established the threshold of reproduction, it is easy to explain why *Capnodis* oviposit at certain hours of the day only. Observations on captive females show that egg-laying during the spring is confined to the warm midday hours. In the summer months, however, egg-laying may begin as early as 9 or 10 o'clock in the forenoon. In other words, only during the hours when the temperature rises above 26° C. does egg-laying take place.

Two-hourly egg counts of ten females of *C. tenebrionis* were made over a period of 10 days in July, 1943. 82 per cent. of the eggs were laid during the middle of the day and that a few were laid early in the day can be explained by the fact that the temperature often rose above 26° C. as early as 8.30 a.m.

Similarly, one can explain the reason for oviposition taking place only in the summer. Very few eggs are laid during April, and those only on very warm days and in the warm hours of the day, when the temperature rises above 26° C.

Egg-laying records of captive females bred outdoors in Rehovoth for several years, show that normal egg-laying begins in May and increases throughout June, July and August. Towards the end of August a steady decrease occurs until early October, when oviposition ceases entirely. This rest period continues throughout the winter until warm weather again sets in. Females may complete their egg-laying in one summer, if they happen to mature very early in the summer and begin laying in June, but very often the egg-laying period extends over two summers with the long winter intervening. If the females start laying towards the end of the summer, only a small number of eggs are laid then, and the bulk are laid the following summer. On the other hand, if egg-laying begins early, or in the middle of the summer, most of them are laid that same summer and few are oviposited the following summer. Among the captive females, there were quite a few that were prolific over two summers. The most prolific females were those completing their egg-laying in one summer.

Where does Oviposition take place?

In spite of a thorough search, no eggs were found in the grove by the writer. Farmers who "worm" the roots find the larvae quite easily but have never reported having seen the eggs of *Capnodis*, and the following views on where egg-laying takes place in nature are based on experimental evidence and field observations.

In confinement the eggs are laid on the bottom of the glass jar or along the corner of the cage in masses and either pasted together on the glass, or loose. Occasionally an egg or a few eggs are laid on the twig supplied as food. Eggs pasted on the leaves of the food plant in confinement were common, especially with *C. cariosa*. Eggs laid in masses and pasted to the bottom of the jar were often covered with faeces. When a small section of an almond branch, a cylinder 8 cm. high and 5 cm. in diameter, was placed in the breeding jar, most of the eggs were laid on it, in particular in any crevice, depression or hole or along a ridge in the bark.

A field experiment was carried out to ascertain whether *Capnodis* would oviposit under natural conditions on the trunk or branches and for this purpose a bottomless cubical cage $1\frac{1}{2}$ metres in dimension was placed over a young plum tree. The earth around the tree was covered with a piece of dark cloth and tied well around the trunk in order to prevent the beetles from hiding or escaping into the ground. Two laying females of *C. carbonaria* were released in this cage. A week later the cage was removed and it was found that a few hundred eggs had been laid. Only two eggs were found attached to the trunk; about 20 were laid in a fold of the cloth, and the rest were found between the lower edges of the walls of the cage and the cloth. The space between the edges of the cage and the ground was as a rule too close for the beetle to penetrate except with the tip of the ovipositor. Most of the eggs were flat and pasted either to the cloth or to the bottom of the wooden cage.

The experiment was repeated with another tree, and similar results were obtained, indicating that *Capnodis* tends to descend from the tree to the ground to oviposit, and that, as a rule, the female chooses crevices or concealed nooks in which to lay her eggs.

Hence, an ideal place for oviposition is the space between the trunk and the earth around it. This space, which is caused by the bending of the tree with the wind, is sufficiently large to permit the entrance of the beetle; it is dark, and there are suitable crevices, either in the ground or on the trunk, or between the main roots. Evidence that this is the case may be derived from the fact that as a rule young larvae are found in large numbers in the roots close to the root crown, and that the highest percentage of infestation occurs in this position. A piece of rock, or block of earth under a tree, may also serve as a place for oviposition. This is confirmed by the fact that larvae may often be found in roots about $\frac{3}{4}$ of a metre or more distant from the trunk. In one instance, in Mizra, a larva was found about $1\frac{1}{2}$ metres away from the trunk, and no connecting galleries were found between this section of the root and the root crown. Apparently the larva, having hatched from an egg on the surface of the ground, penetrated immediately into the ground and discovered the root into which it penetrated. It is not likely that the larva crawled away from the trunk in order to enter the ground elsewhere, nor is it likely that it burrowed so far from the trunk in order to enter a root at a remote place. The tendency of the larva is to enter the earth in its immediate vicinity, unless it encounters some obstacle.

An egg or a few eggs may be laid or pasted on the twigs or leaves, but as soon as they hatch the larvae drop to the ground and enter it in search of a root, and this leads to infestation either near the crown or far removed. A larva sometimes drops into the fork of two or three branches, and since the tendency is to penetrate downwards, it begins to gnaw and dig itself into the bark of the tree, which may be far above the surface of the ground. Several such cases were observed in Beth-Shlomo, Mikveh-Israel, and Pardess Hanna, in which the gallery of the larvae began in the

fork of the main branches, and extended downwards, becoming wider and wider as it advanced. The only plausible explanation of such an infestation is that the larva dropped from an egg laid on the tree, or that the egg itself was laid or dropped thereon. These are exceptional cases, and are not as serious as the usual type of infestation, near the root crown, which is most severe because of its abundance, and ill effects.

Length of Life of the Adult.

Almost all of the individuals reared by the writer were adults that had been captured in the grove or orchard. Since no exact date of their emergence from the pupae is available, no accurate information regarding the length of their life can be obtained from these records. The actual length of life of the beetle, therefore, is longer than the figures given below. Many of the beetles, captured during the spring and summer, died during the same summer, others died at the approach of winter, whilst others over-wintered and continued to oviposit the following summer. Thus, of 35 *C. carbonaria* caught in April, 1938, eight only lived less than 50 days, 10 lived for a period of from 50 to 100 days, while 17 lived over 100 days; of these, five females laid the following spring. Three females of *C. carbonaria* caught in August, 1936, died in July, 1937; at the time they were caught they were ovipositing, and if the pre-oviposition period is added, it is safe to say that they emerged at least during June, 1936. In other words, they lived over a year. Two specimens of *C. tenebrionis* were captured in August, 1937, and died in April, 1939. Records of the longest-lived beetles of these species is given in Table 1.

C. carbonaria did not live more than two days at a temperature of 45° C., and of 25 beetles 22 were found dead the following day, while three died on the third day.

From the foregoing it is apparent that *C. carbonaria* or *C. tenebrionis* may live over a year, and on rare occasions two years, and oviposit during two successive summers.

Habits and Phenology.

Unlike other Buprestids, *Capnodis* beetles feed on the bark of the soft twigs and not on the leaves. Their mandibles are not sharp and do not close sufficiently to cut the leaves; they tear off the soft bark and chew rather than cut it. Twig buds are their favourite food; the stalks of the leaves around the bud are also readily eaten and the leaves drop to the ground. Fresh leaves on the ground may disclose the presence of the pest on the tree. During cold, humid weather, overwintering beetles hide in the ground but on warm days, during the winter months, some of the beetles may crawl out to sun themselves. Quite a number of beetles, for instance, were captured in an almond grove in March. On such occasions they were usually found on the main trunk, with their backs to the sun, in order to secure the maximum benefit from the sun's rays.

The largest migration of beetles from the ground to the trees takes place in April. These are all over-wintering beetles, for new adults do not emerge before May and June.

Activity.

A diapause in the true sense of the word, such as we find in certain Coleoptera or Lepidoptera, does not exist in the case of *Capnodis*. Low temperature or humidity merely decreases the activity of the beetle, but should a hibernating female be placed during the winter in a thermostat at a temperature sufficiently high for oviposition, she will lay eggs, provided she is in a condition capable of so doing.

In captivity beetles ceased feeding during the winter, when the temperature dropped to about 20° C., but when placed in a thermostat at a higher temperature, feeding was resumed and continued to be normal so long as they remained at the high temperature.

When the temperature rises above 32° C. the adult of *C. carbonaria* and *C. tenebrionis* become restless. In captivity adults begin to buzz and attempt to fly, but in the field they either fly or seek shelter from the heat, and those on the tree are usually to be found on the shady side of the trunk or between the leaves. Careful observation of *C. cariosa* shows that the insect is found on the tree only when the temperature is between 26–30° C.; when above 30° C. they either fly or hide themselves. Observations throughout the year show that *C. cariosa* appears only in May and disappears in November. During July and August the insect is found on the trees both in the morning and afternoon but in other months it may be found especially at noon.

The activity of the beetles may be summarised as follows:—

Below 20° C.	.. Inactivity.
About 20–22° C.	.. Threshold of activity.
About 25–26° C.	.. Threshold of reproduction.
About 28–33° C.	.. Optimum temperature for egg-laying.
Over 33° C.	.. Increased activity and flight.
Over 45° C.	.. Most of the beetles die within a day.

A MACHINE FOR NICOTINE FUMIGATION OF FIELD PLOTS.

By A. R. Wilson, Ph.D.

Midland Agricultural College, Sutton Bonington, Loughborough.

(Plates III and IV.)

In the course of work on virus yellows of sugar beet in 1940, it became necessary to have some readily available method of killing Aphids on plants in field plots. Hand spraying with nicotine solution proved very slow if done thoroughly enough to give a satisfactory cover of the foliage. After seeing in operation a machine for large-scale nicotine fumigation of field crops, it was decided to examine the practicability of constructing a small, much simplified fumigator for experimental work. As the design of any machine of this type is covered by British Patent No. 536,585 the project was communicated to the patentees,* who kindly granted a free licence. The patentees have recently indicated that they are prepared, on application, to grant a free licence to other research workers desirous of making one of these machines for their own use.

The main requirements of the machine were considered to be :—effective fumigation ; simple construction, as it had to be made with the limited facilities of the local blacksmith, from readily available materials ; ease of transport, permitting use on widely separated experimental sites ; robustness, to withstand towing behind a car for considerable distances ; ease of handling in confined areas, essential in plot work ; minimum mechanical damage to crop ; ease of adjustment, as the machine was intended for use on both beet root and seed crops, thus necessitating frequent alterations for clearance and row width ; low initial and operational cost.

Construction.

As the fumigator was constructed almost entirely from standard plumbing fittings, angle iron, strip iron etc., built round second-hand motor-cycle parts, exact measurements are obviously of little value as parts available to others will almost certainly differ from those used here. Drawings, with the exception of fig. 7, are to scale and any dimensions omitted in the text can, therefore, be ascertained by measurement with sufficient accuracy for practical purposes.

In the early stages it was decided that traction should be by hand as the transmission of power to the wheels, in a machine adjustable for both clearance and row width, would have been relatively complex and would have added greatly to the cost.

Throughout the text, reference to any point in the drawings is by a number in brackets, the same number being carried through the various aspects of any part.

Chassis Frame.—This consists of two rectangles of angle iron, 46 in. × 30 in. (internal) placed one above the other and joined by 5 in. vertical lengths at the corners. The internal angle faces outwards and downwards at the top and inwards and upwards at the bottom. The angle iron used was 1 in. × $\frac{1}{4}$ in. in the bottom section and 1 in. × $\frac{1}{8}$ in. in the top section and verticals. Cross members (1), top and bottom, welded approximately 16 in. from the front, form the back containing bars for the toolbox. Two lengths of $1\frac{1}{2}$ in. × $\frac{1}{4}$ in. angle iron (2) are welded, 10 in. apart, across the bottom section, the forward one approximately 24 in. from the

* Messrs. Pest Control Ltd., Harston, Cambridge.

front. These carry the engine assembly, fuel and nicotine tanks. Additional lengths of angle iron are welded to the front of both rectangles of the frame (3); the box section so produced gives the additional strength necessary to withstand the strains imposed by the front leg (5).

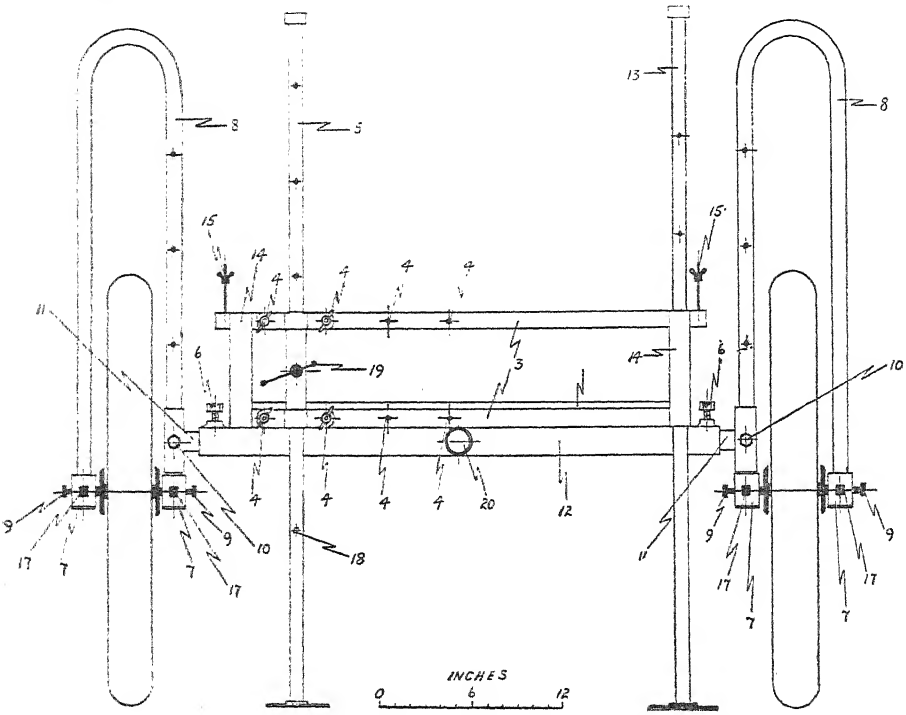

FIG. 1.—Front elevation of chassis.

Axle Assembly.—The spindles of the motor-cycle wheels used had to be supported on both sides as it was found necessary for long road haulage to keep the ball races intact. For the sake of rigidity and to obviate twisting stress at the track adjustment screws (6), a tubular, double U form of suspension was adopted. Each wheel spindle is carried in holes drilled in the centre of two lengths of 2 in. × $\frac{3}{8}$ in. strip (7) bent at each end to form sockets, 12 in. apart centre to centre, for the vertical suspension tubes (8). These are of $\frac{3}{4}$ in. B.S.P.* cross-braced at the top. They are held in sockets by $\frac{1}{2}$ in. set screws† (9) passing through one wall of the tube and tightening against the other, thus permitting rapid removal of the wheels for tyre changing. Large washers welded to the bottom of the sockets prevent the hole in the tube passing beyond the level of the set screw. The inner arm of each U of the wheel suspension is provided with countersinks every 6 in. to give clearance adjustment by means of the $\frac{1}{2}$ in. set screws (10) on the vertical tubes of the track adjustment bars (11). These vertical tubes should be a good sliding fit on the wheel suspension arms. The track adjustment bars are of $1\frac{1}{4}$ in. B.S.P. and are provided with countersinks every 3 in. along the top. These slide into lengths of tubing (12) welded across the bottom of the frame and projecting 2 in. on either side. These tubes are 12 in.

* British Standard Pipe.

† All set screws were made by drilling a clearance hole in the outer tube, over which was welded the appropriate nut.

apart centre to centre, the back one being approximately 12 in. from the rear of the frame. ½ in. set screws (6) on the projecting portions, in conjunction with the countersinks on the track adjustment bars, provide the means of adjusting the track. The height of the suspension tubes is approximately 30 in. and the length of the track adjustment bars approximately 16 in., giving, with the wheels used, a clearance variable between 16 in. and 34 in. and a track variable between 43 in. and 67 in. Careful attention should be paid to the point of balance of the machine, therefore, the track adjustment bar housings (12) should not be welded in position until the last. The machine should be slightly forward, heavy without the toolbox and with the drag sheet spread out for fumigation.

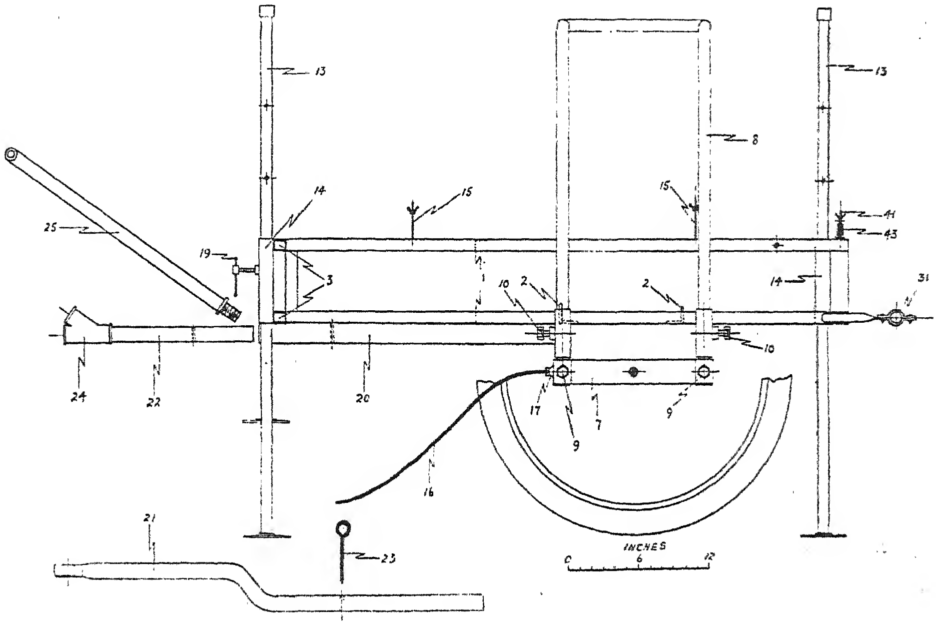

FIG. 2.—Side elevation of chassis.

Jacking System.—In order to facilitate track and clearance adjustment, a simple jacking system is incorporated. Four lengths of ¾ in. B.S.P. (13) are fitted with end caps; the other ends are threaded to take 4½ in. diameter sole plates. Four $\frac{5}{16}$ in. holes, 6 in. apart, are drilled through each pipe, the first approximately 8 in. below the end cap. 7 in. lengths of tubing, an easy sliding fit on these, are welded at the four corners of the frame (14). Four pins of ¼ in. rod, tapered at one end and bent into a loop at the other, are inserted at the lowest holes in the sliding tubes, immediately below the lengths of tubing welded to the frame. At the lowest clearance setting this should raise the wheels an inch or so off the ground. Working from one end then the other, the whole machine can be raised in steps of 6 in. by one man, the pins being withdrawn and placed in the hole higher up on each occasion. The machine is lowered by reversing the operation. When not required, the sole plates of the jacks are removed and stored in the toolbox and the jacks themselves withdrawn and clamped on the bolts on the top side frame members (15).

Leaf Guards.—These consist of approximately 22 in. lengths of ⅜ in. rod bent to shape and threaded at one end (16) to screw into nuts welded to the front of each axle mounting strip (17). Lock-nuts are provided. For road haulage the leaf guards are carried in the tool box.

Leg.—This consists of a length of 1 in. B.S.P. (5) fitted with a $4\frac{1}{2}$ in. diameter sole plate at the bottom and an end cap at the top. Countersinks are provided every 6 in., the lowest at the position necessary to support the chassis level when at the minimum clearance setting. A $\frac{1}{2}$ in. hole is drilled through one wall of the pipe approximately 11 in. from the bottom (18). A 7 in. length of tubing, a good sliding fit on the leg, is welded to two U collars of 1 in. $\times$ $\frac{1}{4}$ in. strip, the wings of which are drilled to fit over the lateral adjustment bolts (4), of which four are provided, 4 in. apart, top and bottom, thus allowing 8 in. of lateral adjustment. This is essential in order that the leg may always fall between two rows when in use. A $\frac{1}{2}$ in. set screw with sliding tommy bar (19), in conjunction with the countersinks on the leg, provides the means of vertical adjustment. For road haulage the leg is drawn up and the set screw turned home through the hole drilled in the wall of the leg.

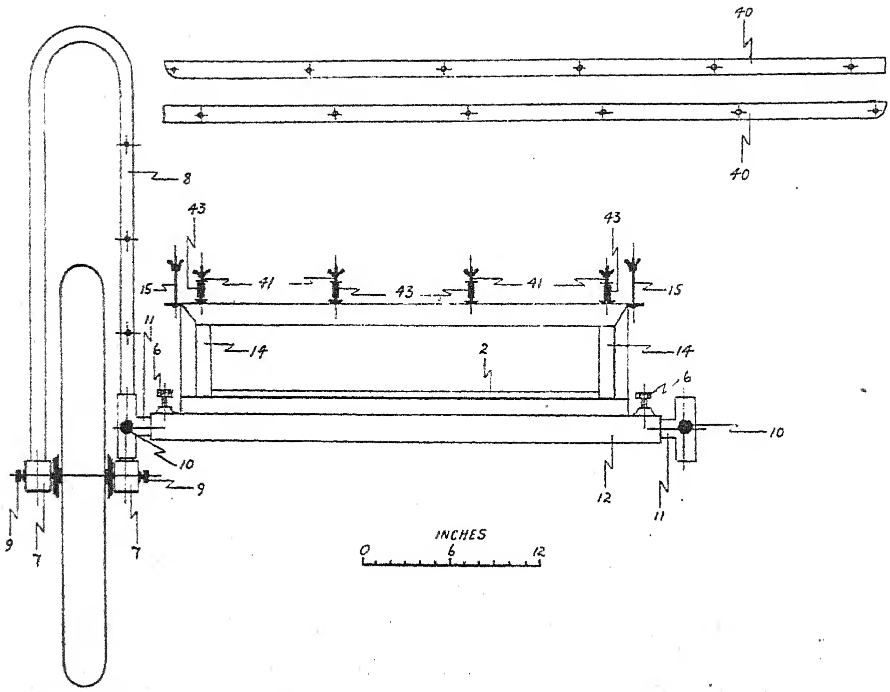

FIG. 3.—Back elevation of chassis and detail of boom.

Traction.—A length of tubing of a size to take 1 in. B.S.P. as a sliding fit, is welded longitudinally below the frame (20), the rear end to the forward track adjustment bar housing. The front end is flush with the front of the chassis frame. A $\frac{5}{8}$ in. hole is drilled through this approximately 5 in. from the front. This tube is the housing for a tow-bar (21) or the bottom bar (22) of the hand draw-bar (25), both of which are made of 1 in. B.S.P. drilled with a $\frac{5}{8}$ in. hole to register with the hole in the housing. The tow-bar or draw-bar is held in place by means of a length of $\frac{5}{8}$ in. rod tapered at one end and looped at the other (23). The bottom bar of the hand draw-bar is fitted at the forward end with a 45° angle union (24) so that alternative heights of handle are available for use according to the clearance level of the chassis frame. A T-handle is welded to the top of the hand draw-bar (25) and this is fitted with motor-cycle handlebar grips; the lower end is threaded to fit into the union on the bottom bar and is provided with a pair of lock-nuts which are tightened when the handle is first screwed home to the correct position.

Engine.—The engine is a 150 c.c. two-stroke. A two-stroke unit was selected for several reasons, the chief ones being high exhaust temperature, simplicity and ease of starting. As there is no load on the engine the flywheel had to be weighted to obtain steady running. This was accomplished by brazing an "Austin" 7 crown wheel on to the inner face. The flywheel itself is grooved for cord starting, a hole being provided for an end knot on the cord (26). Air and throttle levers are mounted on one of the tank supports (27). Petroil and nicotine respectively are contained in one gallon cylindrical tanks of heavy gauge tinned iron mounted on 1 in. by $\frac{1}{8}$ in. strip iron frames attached to the angle iron engine supports of the chassis frame (2). Owing to considerable vibration, it was necessary to stay these tank mountings (28) to the top section of the chassis frame. The petroil tank is fitted with a filler cap and a motor-cycle tap, the latter with an integral filter. A fan is mounted on a shaft on the opposite side of the crankcase from the flywheel and protected with a sheet iron shield (29). This fan provides adequate cooling for long periods of continuous running.

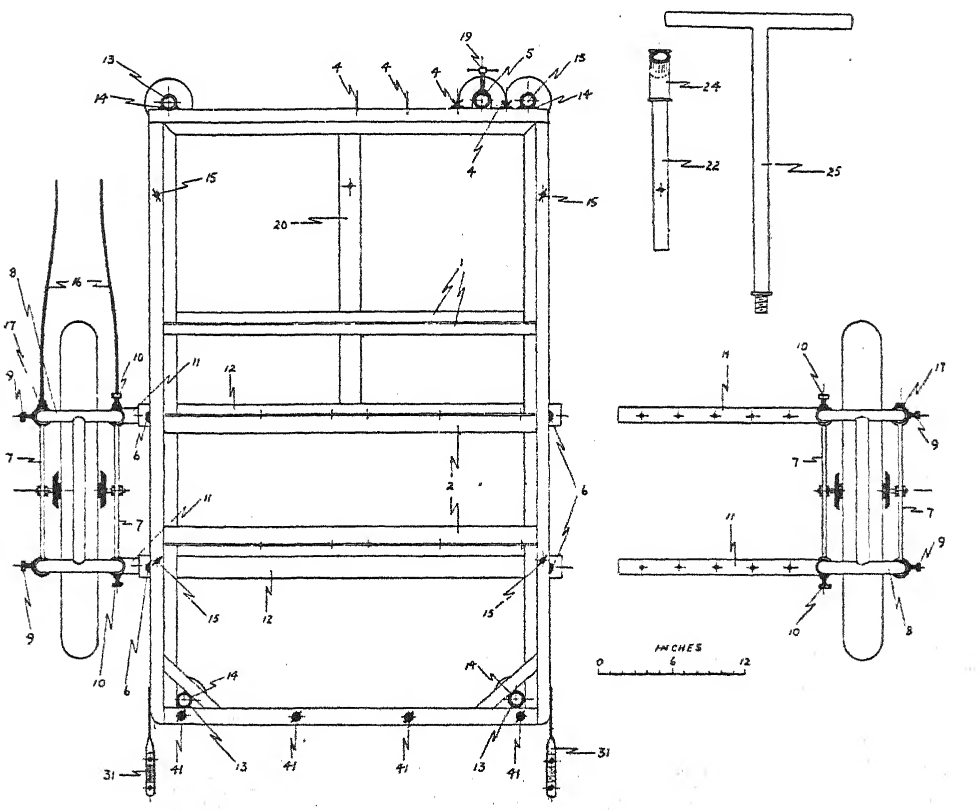

FIG. 4.—Plan of chassis.

Exhaust System.—The exhaust pipe is of $\frac{3}{4}$ in. B.S.P. and is brought out from the port horizontally for 6 in. then angled down behind the bottom back member of the chassis frame to a reducing T junction (30). Approximately 22 in. lengths of $\frac{1}{2}$ in. B.S.P. screw into this and are held by clips of 1 in. × $\frac{1}{4}$ in. strip iron welded to the rear end of each of the bottom side members of the frame (31). The ends of these pipes carry unions (32) into which screw extensions of the same bore (33). These extensions are approximately 24 in. long and are closed at the end with screw

caps. In this horizontal part of the system holes are drilled every 4 in., which, in order to distribute the gases evenly, are graduated in diameter from $\frac{5}{64}$ in. at the centre, by $\frac{1}{64}$ in., to $\frac{1}{4}$ in. at the outside. The exhaust pipe above the T-junction is lagged to within 2 in. of the port with several thicknesses of asbestos string, covered in turn with a layer of insulation tape and finished with a coat of paint. The extension pipes are fitted with lock-nuts (34) so that the holes can be correctly lined up when the extensions are screwed in. The holes should point downwards and slightly backwards. For road haulage the extensions are carried in the toolbox.

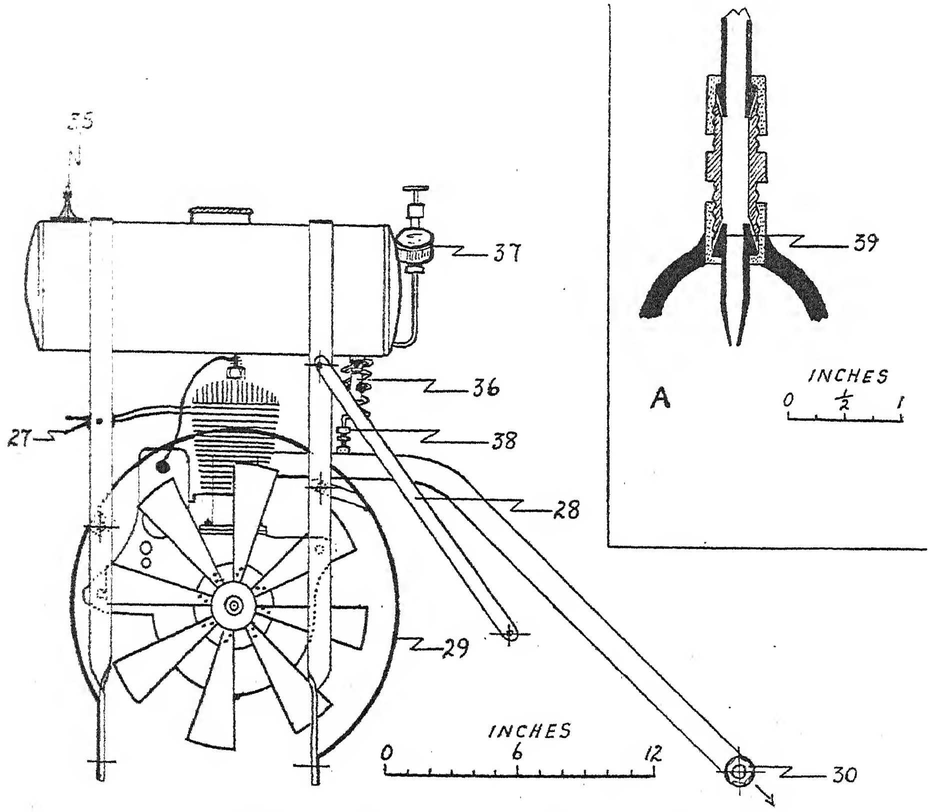

FIG. 5.—Side elevation of engine, nicotine and exhaust assembly. A. Vertical section through nicotine injector.

Nicotine System.—The nicotine tank is, as stated above, similar to the petroil tank. It is fitted with a syringe top as a filler cap, through which is soldered a Schrader valve (35). The tank was tested to 50 lb. per sq. in. and for working is pumped with a motor-cycle pump to 20 lb. per sq. in. (tested with tyre pressure gauge). A drain tap (36) is fitted. The nicotine is forced up a tube from the bottom of the tank to an adjustable motor-cycle drip feed (37) by means of which the dosage is regulated, thence through copper tubing to the injector (38), which enters the exhaust pipe 2 in. from the port. This unit is composed of standard motor-cycle pipe unions (fig. 5A). On account of heat, the injector nipple is brazed instead of soldered to its ferrule (39) and the bottom nut brazed to the exhaust pipe. The nipple is readily removable for cleaning.

The drops of nicotine entering the exhaust pipe immediately vaporise as the temperature at the injector nipple is over 350° C., which is considerably in excess of the boiling point of nicotine. Decomposition is largely prevented by the rapidity of removal of the vapour in the exhaust stream and the relatively quick cooling which occurs. Rough temperature measurements taken in the distributor pipes approximately 6 in., 24 in., 36 in. and 66 in. from the T-junction were 125° C., 78° C., 51° C. and 22° C. respectively. These figures show that condensation must occur in the pipes but, owing to the high initial dilution of the nicotine vapour, it is apparently of little consequence.

The Boom.—The boom for carrying the drag sheet consists of two 48 in. lengths of 1 in. × $\frac{1}{4}$ in. angle iron (40). These are drilled with $\frac{7}{16}$ in. holes spaced 9 in. apart centre to centre. The boom sections are placed over the $\frac{3}{8}$ in. fastening bolts on the top back chassis frame member (41) so that the inner angle faces upwards and backwards. These four bolts are 3 in. long and are held in position by nuts which are tightened down over the four centre eyelets of the sheet (42). The two inner holes of the boom sections are placed over these and 1 in. long spacing tubes (43) slipped on; next come washers and finally wing-nuts. For road haulage, one section is moved inwards and the centre four holes slipped over the bolts; the other section is turned round so that the inner angle faces up and inwards and placed on top of the first. The spacing tubes and washers keep the wing-nuts clear.

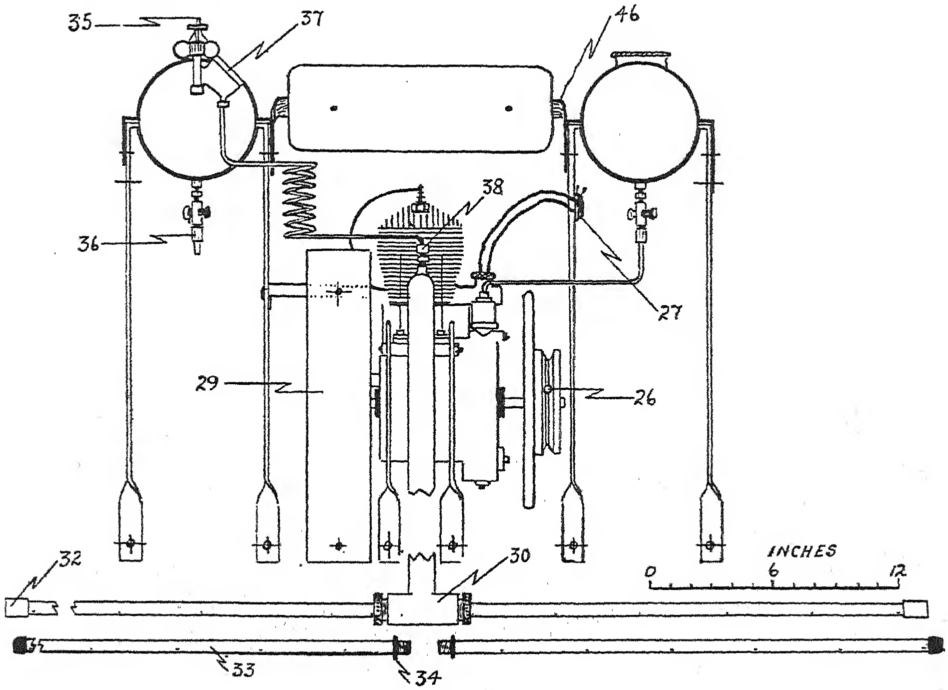

FIG. 6.—Back elevation of engine, nicotine and exhaust assembly.

The Sheet.—The sheet is made of close weave canvas and is 12 ft. long by 8 ft. 4 in. wide (fig. 7). Tapering side flaps and an adjustable back flap are provided. As the back flap falls in front of the horizontal distributor pipes it is cut to fit over the main exhaust pipe. For working at low clearances this flap is folded upwards and held by turn-buttons (44). The four centre eyelets (42), held under nuts on the boom

fastening bolts, are never moved. When the boom is extended, the hooks (45) either side of these are placed in the holes in the boom sections. Provision is made for the attachment of extensions in length to the sheet (fig. 7). For road haulage the sheet is strapped to the boom and back of the chassis frame (Pl. III, fig. 1).

The small size of the sheet and the heavy weight of the material used were determined by two considerations, manoeuvrability and durability respectively, as the machine was intended primarily for use on small plots. Latterly it has been found preferable to use an extension of 6 ft., thus making the total length 18 ft. Although the weight of the canvas makes further extension undesirable, a sheet made from suitable light cotton material could be considerably longer, thus increasing the speed at which the machine is moved.

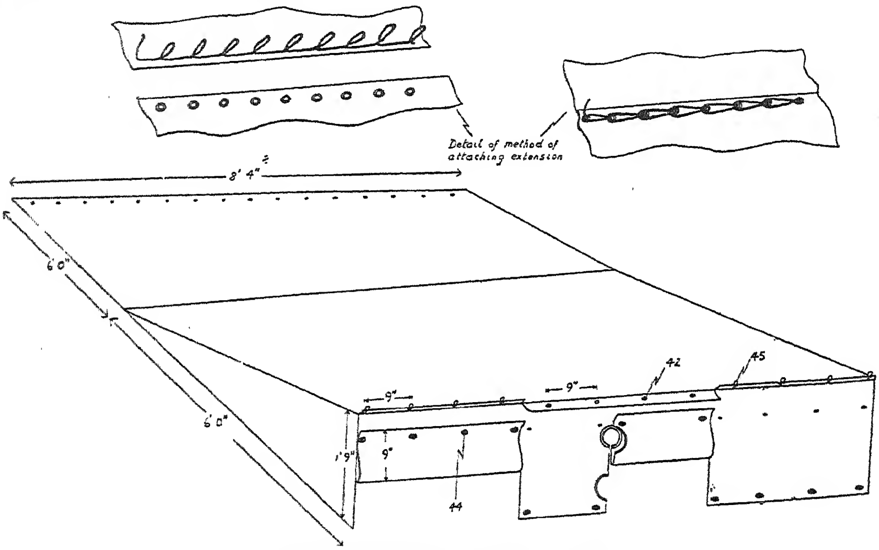

FIG. 7.—Perspective drawing of sheet.

Toolbox and Accessories.—The toolbox is carried in the cradle at the front of the chassis. A hole is drilled in the bottom to take the tow-bar pin. When the machine is in use the toolbox is removed. When ready for the road the contents consist of :—bottom bar and handle of hand draw-bar ; two lateral extensions to exhaust distributor pipe ; four leaf guards ; four sole plates and pins for jacks ; petrol tin ; tin of oil ; tin of nicotine ; oil can ; quantity of cord ; starting cord ; spare spark plug ; filling funnel with filter ; respirator (nicotine proofed) ; cotton waste ; wire brush for cleaning plugs ; tyre pressure gauge ; motor-cycle pump ; puncture repair outfit ; hammer and tool-roll containing a set of six spanners, tyre levers, pliers, screwdriver, etc. Straps are provided on top of the lid to carry the sheet extension when not in use. It is essential to partition the toolbox and to make sure that the contents fit snugly in view of the vibration and shocks sustained on an unsprung chassis.

Miscellaneous.—The number plate necessary for road haulage is carried on a length of strip iron attached to the tank supports (46). For transport in bad weather a waterproof canvas cover, carrying a painted number plate, is provided.

Cost.—The cost of the materials and blacksmith's time to produce the machine in 1941 was approximately £30. A proportion of the actual constructional work was, however, done by the writer.

The Machine in Use.

Operation.—After adjusting track, clearance, etc., extending the boom and sheet, the engine is warmed up for a few minutes before the nicotine is turned on. When using an 18 ft. long sheet the drip feed is adjusted to give a flow of 20–30 drops per minute. In practice, however, at this slow speed, the drip feed has proved somewhat erratic and the best guide to the correct dosage is the density of the fumes coming out below the far end of the sheet; these should appear as a thin white mist. The feed must be adjusted according to wind conditions and the speed at which the machine is being moved. The rate of movement should be roughly the length of the sheet per minute, but when large plants are being treated, in calm weather, the vapour persists among the leaves and the speed may be increased. With the 18 ft. sheet, on a straight run, fumigation of one acre takes approximately five hours. The use of a 54 ft. long sheet would reduce the time taken to about $1\frac{3}{4}$ hours and would enable the machine to be drawn by a tractor if desired. It should be emphasised that neither of these suggestions have been tried. The necessity for frequent turning greatly increases the time taken per acre. The amount of nicotine required per acre depends on weather and other conditions but is usually between 800 c.c. and 1,000 c.c. It should be noted that the use of a long sheet would entail running the engine at a higher speed to obtain more rapid vaporisation and distribution of the nicotine. It is necessary to exert an even pull on the draw handle as sway causes the sheet to pump out the vapour. Normal precautions are necessary in handling the nicotine and the use of a respirator specially proofed against nicotine vapour is essential with a following wind or when turning the sheet. Two operators are normally necessary, particularly when dealing with areas over half an acre where the factor of fatigue must be considered. On completing work the nicotine should be turned off some minutes before the engine.

Weather.—Ideally, fumigation should be done on a calm, warm day, on dry plants. It is not practical to use the machine in any degree of wind as even if the sheet does not blow about, the nicotine vapour is blown from under it. Suitable conditions frequently occur on summer evenings.

Maintenance.—The spark plug should be cleaned with a wire brush before starting. At longer intervals the nicotine injector nipple should be removed and cleaned and the exhaust system dismantled and scrubbed out with a wire brush. Carbon deposition is heavy in the restricted exhaust passages. Little servicing of the engine has been found necessary beyond occasional decarbonisation. Nicotine should be filtered before use and the nicotine tank washed out at the end of the season. During many hundreds of miles of towing, including individual journeys of over 100 miles, no repair to the chassis has been necessary.

Results.

The machine has been used successfully to kill Aphids infesting sugar beet seed and root crops and potatoes during the past four years. Tests of performance carried out on three occasions on experimental plots showed a kill of 88, 93 and 99 per cent. of Aphids respectively.

While one fumigation has been found sufficient to control Aphids introduced experimentally to infect sugar beet plants with virus yellows, on account of the rapid re-infestation from natural sources which often occurs, frequent fumigation may be necessary if it is desired to maintain the aphis population at a low level over long periods.

Acknowledgements.

This work formed part of a programme of research on diseases of sugar beet carried out for the Sugar Beet Research and Education Committee of the Sugar Commission, at the Midland Agricultural College, under the direction of H. H. Stirrup, M.Sc.

The writer is especially indebted to his colleague Dr. R. Hull for carrying out the field tests, for supplying the operational data and for many helpful suggestions during the progress of the work. Thanks are also due to Messrs. Pest Control, Ltd., Harston, Cambridge, for permission to build the machine, to Dr. W. E. Ripper of that firm, for kindly criticising the manuscript; to V. Stansfield, F.R.P.S., of Rothamsted Experimental Station, for taking the photographs (except Plate IV, fig. 3.) and to the following members of the staff of the Midland Agricultural College :— C. R. Calder, B.Sc., A.M.I.B.A.E., for criticising the manuscript and R. J. Fox, B.Sc., N.D.A., for assistance with the drawings.

Summary.

The construction of an inexpensive, simple, hand-drawn fumigator for field plots is described. The general principle employed is the injection of liquid nicotine under pressure into the exhaust system of a two-stroke engine, close to the port. The liquid is vaporised by the heat of the exhaust stream and distributed by it below a drag sheet at the rear of the machine.

The machine is of simple and robust construction, utilising standard plumbing fittings, angle iron, strip iron and second-hand motor-cycle parts and can, therefore, be made where only limited facilities are available.

The machine is self-contained and easily transportable as it can be towed behind a car from one locality to another. It is suitable for use on a wide variety of crops since the track is variable between 43 in. and 67 in. and the clearance between 16 in. and 34 in. With the 18 ft. long sheet used it can fumigate, in good conditions, one acre in about five hours. It is pointed out that the use of a lightweight sheet about 54 ft. long would decrease the time required per acre to about $1\frac{3}{4}$ hours and would enable the machine to be drawn by a tractor if desired; these suggestions have not, however, been tried.

The machine has been in use since 1941 for controlling aphis infestation in connection with work on virus yellows of sugar beet and has given most satisfactory results. Tests showed that a kill of 88–99 per cent. of Aphids was obtained.

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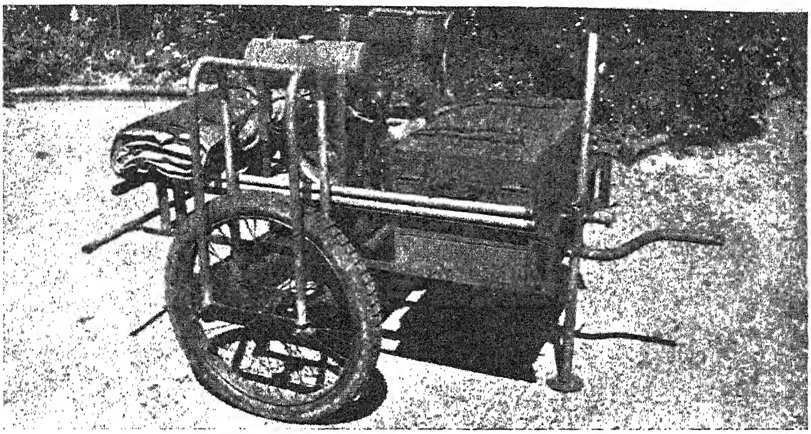

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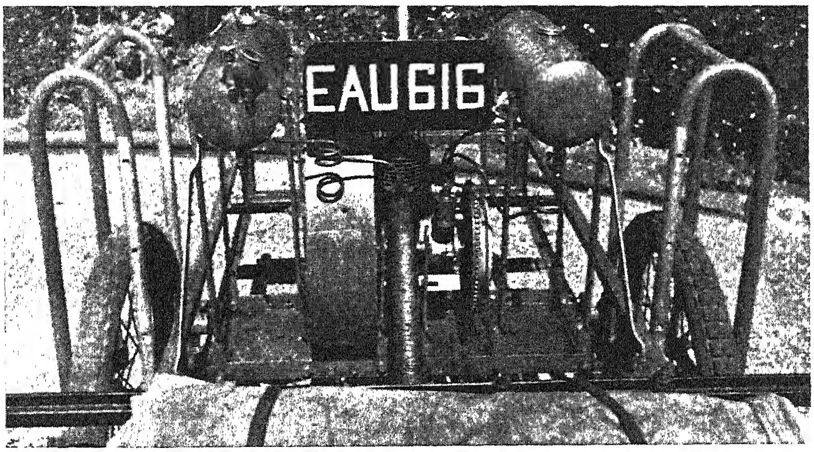

Fig. 2.

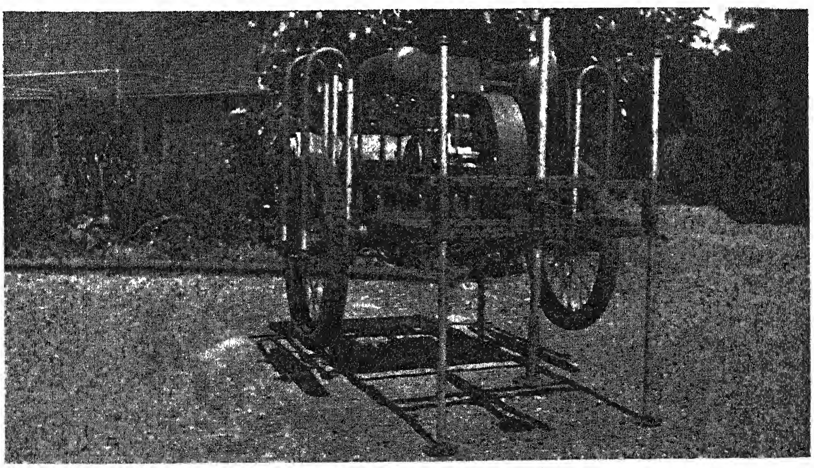

Fig. 3.

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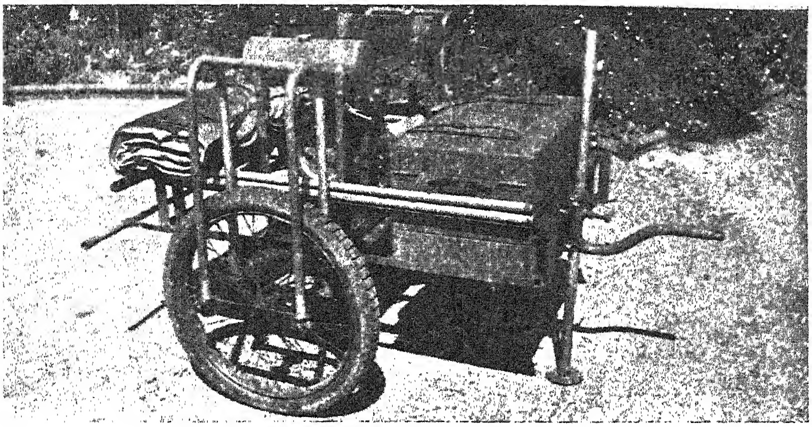
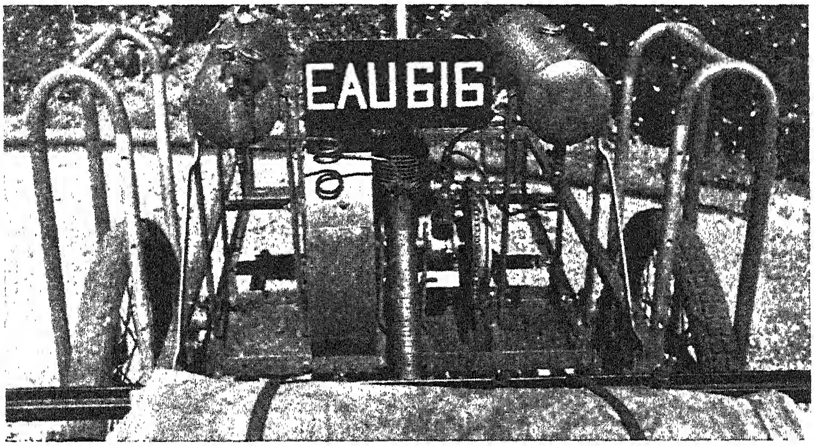


Fig. 1.



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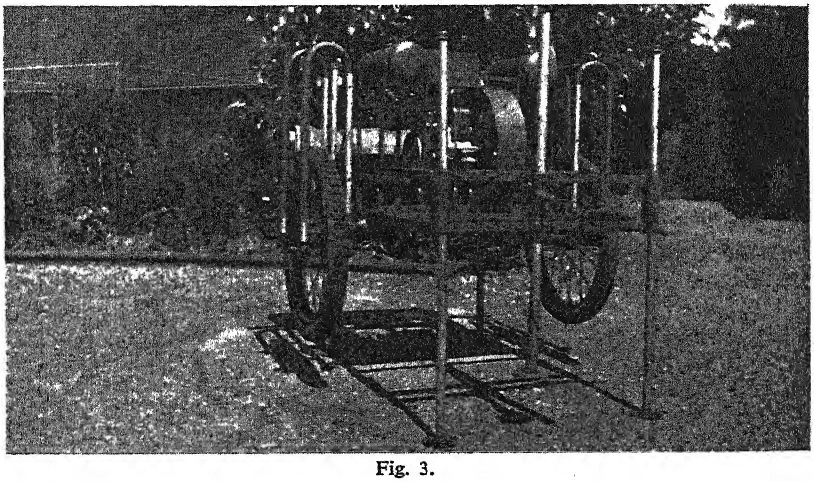
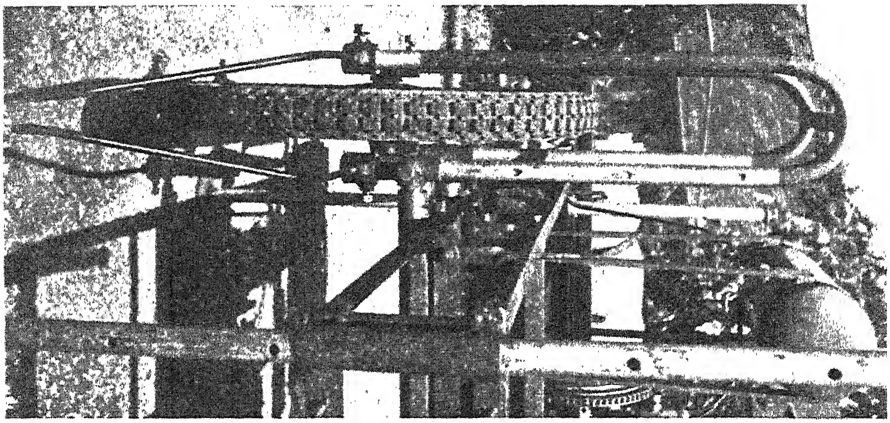


Fig. 3.



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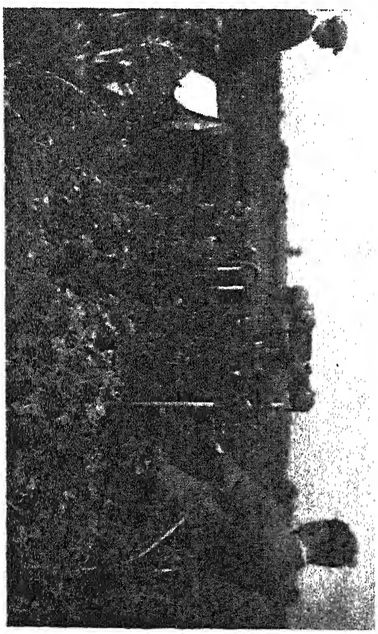

Fig. 3.

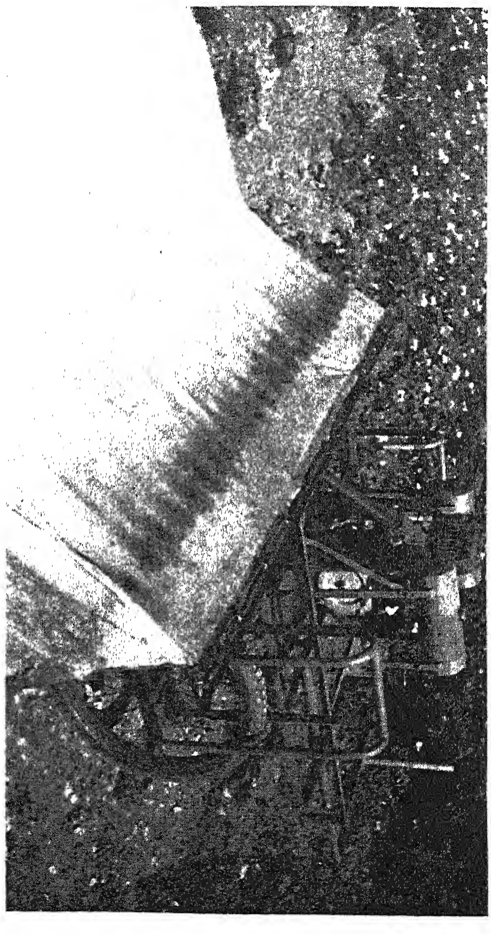

Fig. 2.

AN ARTIFICIALLY ISOLATED GENERATION OF TSETSE FLIES (DIPTERA).

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Method.

About 30,000 pupae of *Glossina morsitans*, Westwood, were collected in the Central Province, where that species is abundant, and sent by rail to Shinyanga, where the indigenous species are *G. swynnertoni*, Austen, and *G. pallidipes*, Austen. They were stored in a refrigerator at 16° C. for a week or two until the full number had arrived, by which time about 5,000 had emerged. A temperature of 16° C. does not prevent emergence entirely, nor does it stop development; but a proportion of flies which have completed their development are inhibited from emerging, and when the pupae are removed to (for them) normal temperatures there is a burst of emergence for the next few days, which in the present experiment produced at least twice as many flies as would otherwise have appeared.

At dawn on 20 July, 1945, the pupae were removed and taken out to the bush, where they were placed in a Stevenson screen. The site chosen was in country inhabited by *G. swynnertoni* and *G. pallidipes*, but was not in a concentration site of either, and only a very occasional stray individual would be caught there.

On the evening of the 22nd the pupae were brought back at sunset. Meanwhile some 3,550 flies had emerged, presumably about half of each sex. The young flies are not normally active during the first two days after emergence, and may be observed perched on the underside of small branches, usually from 6 to 12 feet above the ground and with the head directed outwards from the main stems or trunk unless the branch slopes downward.

The males occasionally attempt to copulate with the females, despite the fact (Mellanby, 1936) that they are not potent for the first few days.

In the analysis of results which follows, all the flies are assumed to have emerged on 21 July, so that in assigning ages to individual flies there is a possible error of plus or minus one day.

The flies were captured, by parties of two individuals carrying an attractant black screen, on a regular route or fly round about 30,000 yards in length, and disposed in a "rectangular spiral" with the release site at its centre. This "spiral" was formed by straight paths, each turning right handed from and at right angles to the previous one, and each exceeding the length of its predecessor by 300 yards, the length of the first of them, which started half its own length from the release site. This arrangement makes the perpendicular distance from any path to the release site half the length of that path. The last path (No. 14) was 4,200 yards long, and was therefore 2,100 yards from the release site at its nearest point. The catchers followed these paths daily from 20 July except on day 49 and on Sundays.

The flies caught were brought back to the laboratory about noon; the *G. morsitans* were placed singly in small tubes ($2 \times \frac{1}{4}$ in.) sealed with wax and including a label on which was written a number corresponding to the sector of the fly-round on which they had been caught. A few additional flies (excluded from Table I) were also received from catchers engaged on other work in the area.

The flies were weighed, usually from 2.30 to 3 p.m., on a torsion balance. One wing was then removed, numbered and mounted. Dry weights were taken until a constant weight (plus or minus ·1 mg.) was obtained, after which the "fat" was extracted in chloroform, again until a constant weight was reached. To allow for the weight of the wing removed, ·1 mg. was added to all dry weights.

The wings were examined under the microscope. The middle part of the fourth longitudinal vein (fig. 1), corresponding to the cutting blade of the hatchet cell, was measured on a scaled eyepiece, and by means of a map wheel and camera lucida,

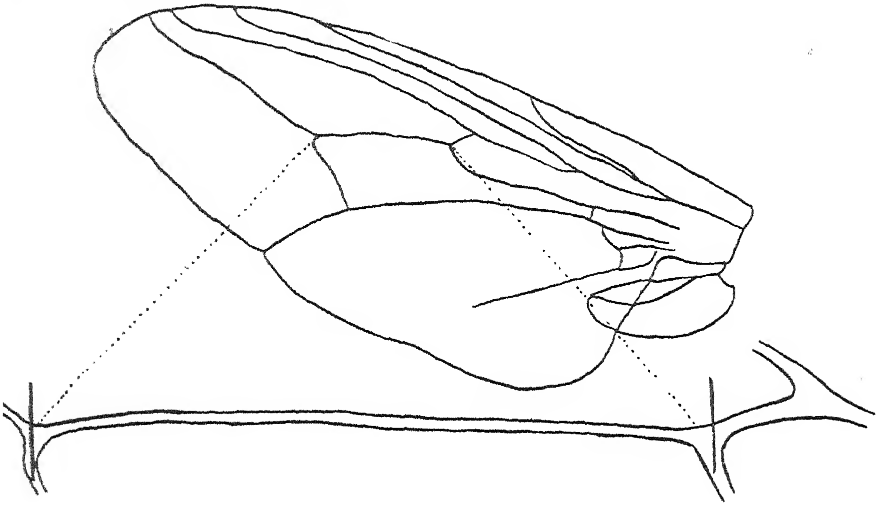

FIG. 1.

the percentage wear on the trailing margin, from alula to tip, was determined. In addition, the wear was estimated by eye under six categories, namely: (1) Perfect; (2) slight damage, possibly accidental, such as might occur in the catcher's net; (3) definite damage, but confined to the proximal part of the margin before the notch; (4) definite damage both before and beyond the notch, but with long, undamaged sections; (5) saw-edged appearance without long undamaged sections; (6) rounded indentations, or with large pieces gone, "tattered". This diagnosis

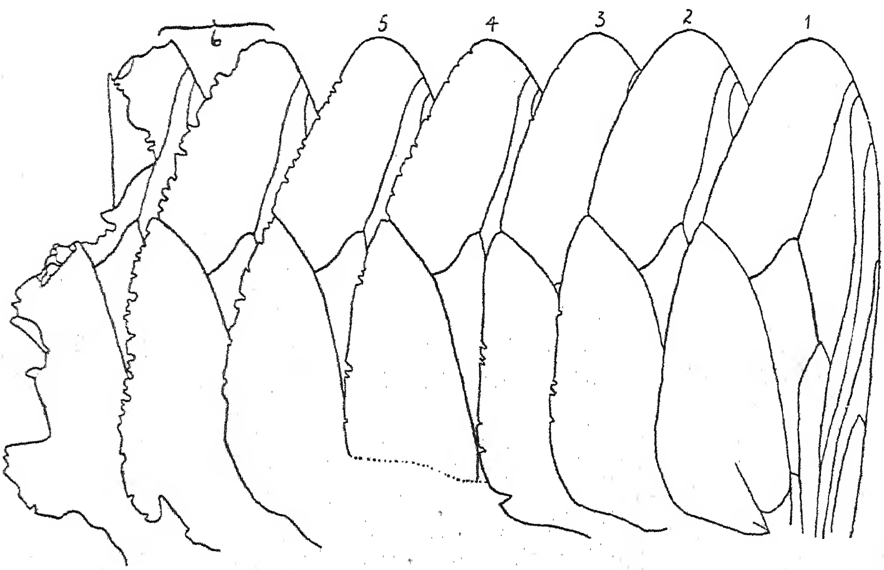

FIG. 2.

TABLE I.
First generation only.

Day.	Teneral. ♂♂	Teneral. ♀♀	Non-teneral. ♂♂	Non-teneral. ♀♀	Males, means. Water, mg.	Males, means. Fat, mg.	Males, means. Residue, mg.	Males, means. Vein, mm.	Males, means. Wear, %	1	2	3	4	5	6	Dispersal.
−1	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
0	1	0	0	0	11·8	1·4	5·4	1·560	0·0	1	0	0	0	0	0	150
1	Sunday															
2	3	4	0	0	12·3	1·5	5·2	1·497	1·0	2	1	0	0	0	0	400
3	9	4	0	0	12·5	1·1	5·2	1·499	0·3	7	2	0	0	0	0	450
4	9	3	0	1	12·5	1·0	5·3	1·519	0·9	6	3	0	0	0	0	417
5	3	5	1	0	15·0	1·2	6·1	1·512	0·2	3	1	0	0	0	0	375
6	0	0	3	2	15·9	1·2	6·5	1·533	0·7	2	1	0	0	0	0	400
7	0	0	2	1	19·8	1·6	8·0	1·495	0·0	2	0	0	0	0	0	150
8	Sunday															
9	2	0	8	1	16·4	1·3	7·0	1·504	3·2	1	9	0	0	0	0	300
10	1	0	5	2	17·7	1·4	7·9	1·527	0·7	5	1	0	0	0	0	281
11	0	0	5	2	16·5	1·3	7·0	1·526	3·8	2	3	0	0	0	0	630
12	0	0	10	0	15·3	1·5	6·7	1·516	3·0	7	3	0	0	0	0	720
13	0	0	10	0	16·1	1·5	7·1	1·487	3·4	6	3	1	0	0	0	495
14	0	0	10	2	17·0	1·7	7·6	1·496	1·4	8	2	0	0	0	0	480
15	Sunday															
16	0	0	4	2	15·5	1·2	7·3	1·502	3·2	1	3	0	0	0	0	788
17	0	0	13	1	18·6	2·7	8·4	1·512	8·2	2	3	7	1	0	0	854
18	0	0	7	3	19·7	3·4	8·6	1·520	3·0	1	6	0	0	0	0	686
19	0	0	5	0	18·7	3·0	8·2	1·516	6·7	0	1	3	1	0	0	630
20	0	0	7	0	17·7	2·9	7·8	1·497	8·4	0	4	3	0	0	0	921
21	0	0	14	0	18·6	3·2	8·1	1·512	9·4	0	1	12	1	0	0	750
22	Sunday															
23	0	0	7	0	17·8	2·9	7·9	1·509	5·3	0	3	4	0	0	0	986
24	0	0	17	0	18·6	2·7	8·2	1·527	8·1	0	5	12	0	0	0	865
25	0	0	9	2	17·1	2·7	7·8	1·507	7·4	0	2	5	2	0	0	900
26	0	0	9	1	17·8	3·0	8·3	1·516	7·9	1	1	3	4	0	0	1,183
27	0	0	4	0	18·6	2·6	8·1	1·485	10·2	0	1	0	3	0	0	1,110
28	0	0	4	0	19·1	3·4	8·3	1·528	14·2	0	0	3	1	0	0	600
29	Sunday															
30	0	0	2	0	17·4	2·7	7·2	1·510	13·0	0	0	1	1	0	0	300
31	0	0	1	0	18·4	1·7	7·7	1·600	20·0	0	0	0	1	0	0	450
32	0	0	2	0	16·2	1·5	7·5	1·490	25·3	0	0	0	2	0	0	1,800
33	0	0	5	0	17·9	2·5	8·5	1·544	14·4	0	1	2	2	0	0	720
34*	0	0	8	0	21·8	3·0	8·9	1·497	23·4	0	0	1	6	0	0	1,012
35	0	0	7	1	18·2	2·4	8·3	1·514	16·2	0	0	2	5	0	0	1,221
36	Sunday															
37*	0	0	10	0	17·5	2·6	8·2	1·527	29·8	0	0	1	6	1	1	1,433
38	0	0	7	0	18·9	2·4	8·6	1·543	16·9	0	0	3	4	0	0	1,329
39	0	0	4	0	17·8	2·6	8·2	1·478	30·2	0	0	1	0	1	2	1,050
40	0	0	6	0	17·8	2·2	8·1	1·505	31·8	0	0	0	3	2	1	1,200
41	0	0	5	0	17·5	2·5	8·1	1·536	38·8	0	0	0	0	1	4	1,170
42	0	0	2	0	19·8	3·9	8·2	1·500	29·5	0	0	0	1	0	1	1,050
43	Sunday															
44	0	0	5	0	17·8	2·0	8·1	1·528	20·0	0	0	1	2	1	1	660
45	0	0	4	1	22·4	3·1	9·6	1·550	37·5	0	0	0	0	2	2	975
46	0	0	2	0	18·7	2·4	7·8	1·475	39·0	0	0	0	0	1	1	900
47	0	0	1	0	15·8	2·4	7·9	1·490	30·0	0	0	0	0	1	0	1,050
48	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
49	No catch															
50	Sunday															
51	0	0	1	0	18·8	1·3	7·9	1·520	39·0	0	0	0	0	0	1	1,350
52	0	0	2	0	20·4	3·5	8·8	1·505	45·0	0	0	0	0	0	2	975
53	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
54	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
55	0	0	1	0	20·1	2·2	8·3	1·470	27·0	0	0	0	0	1	0	900
56	0	0	2	0	19·2	2·8	8·9	1·590	53·0	0	0	0	0	0	2	900
57	Sunday															
58	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
59	0	0	2	0	19·2	3·8	8·2	1·500	48·5	0	0	0	0	0	2	1,725
60	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—
61	0	0	1	1	16·4	1·3	7·9	1·490	47·0	0	0	0	0	0	1	1,650
62	0	0	1	0	19·1	2·6	8·2	1·490	53·0	0	0	0	0	0	1	150
63	0	0	0	0	—	—	—	—	—	–	–	–	–	–	–	—

was assisted by reference to a drawing (fig. 2) showing a typical wing in each category and was done entirely by my assistant, Mrs. Zieskowicz, who also measured the wing veins.

(I afterwards made an independent diagnosis, and disagreed over one fly in four, chiefly by removing flies from categories 1 and 3 to category 2, and from categories 3, 5 and 6 to categories 4 and 5, as well as by border-line discrepancies which cancel each other. The disagreement is so small in the aggregate that it usually makes a difference of less than one day in estimating the mean ages of samples, and I have not therefore interfered with Mrs. Zieskowicz's diagnosis.)

The First Generation of Flies.

Most of the data collected are set out day by day in Table I. The numbers caught are shown in the first four columns, the freshly emerged, teneral flies in the first two, then those which have had a meal and have hardened their chitin. The columns headed 1 to 6 show the number of males assigned to these categories of wing-fray, and the last column shows the mean perpendicular distance of males in yards from the release site.

(*a*) *The Composition of the Catch.*

Most of the teneral flies are caught from day 2 to 3 (4 from the first emergence day), but odd ones continue to day 10; these may have had a partial feed and been incorrectly diagnosed. The non-teneral flies start on day 4 or 5, at first in small numbers only, and increase on day 6 (7 from the first day of emergence). The behaviour of the males is peculiar, in that although some must be dying from various causes they show no fall during the second, third and fourth weeks. This is not explained by errors of random sampling, because it has already been observed in two rather similar experiments carried out in 1944. We have to account for the males, presumed to be dying, being in some way replaced, so that the numbers caught do not fall until the fifth week. There appear to be two possible explanations. It may be that the males are relatively inactive in the early part of their lives; or it may be that they delay to move away from the release site and to appear on the "spiral" fly-round, which, however, starts only 150 yards from the release site. No more were caught after the ninth week.

The females are evidently much more active in the early part of their life, up to about the time (three weeks) when the first larva is dropped. This also has been observed on three previous occasions, and explains the peculiar shape of the survival curve of marked female flies (Jackson, 1941). They do not die quickly, but continue in small numbers as long as the males; this again has often been observed before.

(*b*) *Weight and Size of Males.*

The teneral males contain about 12 mg. of water. As soon as they start to feed this becomes somewhat increased, but does not apparently reach a maximum until about day 17. They start with about $1\frac{1}{2}$ mg. of fat, and this declines to 1 mg. while they are still teneral. After the first meal it recovers to its former level, but, like the water, it does not attain a maximum until the 17th day (in this experiment). The residual weight behaves like the water, except that it is relatively much less in the teneral flies, as different authors have observed before.

Once the maximal fat has been attained it does not appear to diminish, though it is just significantly lower in weeks 5 to 7 than in weeks 3 to 4. After the abrupt rise on day 17 to 18, the fat remains approximately constant, which is not in harmony with Jack's (1939) concept that certain ready feeders continue to accumulate fat throughout their lives. However, the flies in this experiment are not in their

natural environment, in which they are known (Jackson, 1945a) to average a higher fat content. In three similar experiments carried out in different parts of the same area in 1943–44, the maximum fat was also attained in about three weeks, although the experiments were done near to both the hottest and the coldest times of year.

An earlier experiment with marked freshly emerged flies, both *G. morsitans* and *G. swynnertoni*, showed that the males are generally inactive after the first feed until they again become hungry when about a week old. Thereafter individuals which are not very hungry form the bulk of the catch. The hungry flies which reappear after the first feed have a low residual weight relative to the water content, which is then about 71 per cent. of the fatless weight, as opposed to 69 or 70 per cent. in well-fed flies, and 67 or 68 per cent. in hungry flies, after the second feed.

Table I also shows the mean length in mm. of the middle part of the fourth longitudinal vein. It has been shown (Jackson, 1945a, and later observations unpublished) that on the average this measurement bears a relation to the weight of the freshly emerged fly of any particular species, and therefore is an index of the size of the flies. As smaller flies are considered to be less viable (Jackson, 1945a), it had been supposed that the mean vein length might increase with age through the early death of smaller individuals. In Table I, however, there is admittedly no indication of this, the mean vein length remaining very constant throughout.

(c) *Fraying of the Wings.*

The mean percentage wear or fray on the hind margin of the wing is shown (for males only) in Table I day by day. It is negligible in week 1, and thereafter shows a more or less steady increase to about 50 per cent. at the end. Individual flies, however, show considerable variation, which is brought out in the next six columns of Table I, where a few undamaged (1) or slightly damaged (2) wings continue for about 30 days. Moderate damage starts in week 3, and heavy damage in week 6. Thus though the age of individuals cannot be told with any confidence from the fraying on the wings, the mean age of samples can be estimated.

To this end the flies were grouped in 5-day periods (Table II).

TABLE II.

Period.	Days.	Mean fray %.	Square root mean fray %.
1	1–5	0·52	0·7
2	6–10	1·82	1·3
3	11–15	2·74	1·7
4	16–20	5·62	2·4
5	21–25	7·77	2·8
6	26–30	12·08	3·5
7	31–35	19·12	4·4
8	36–40	26·85	5·2
9	41–45	31·22	5·6
10	46–50	36·50	6·0
11	51–55	38·00	6·2
12	56–60	51·20	7·2
13	61–65	50·00	7·1

(This table includes some flies not caught on the "spiral" fly round and excludes a few where the wing was too folded to allow a good estimate of the percentage missing.)

The curve of mean fray per cent. is concave, rising slowly at first and more steeply in its middle and later period. The square root curve, however, is very nearly a straight line and is therefore suitable for the working of a regression coefficient. The correlation coefficient of root mean fray with time is $+0 \cdot 98$, and the regression coefficient of root mean fray on time is $+0 \cdot 5714$. The means are 7 for time (=33 days) and $4 \cdot 162$ for root mean fray per cent. These values lead to the construction of Table III.

TABLE III.

(" Fray " means root mean fray per cent.)

Age.	Fray.	Age.	Fray.	Age.	Fray.	Age.	Fray.	Age.	Fray.	Age.	Fray.
0	0·4	11	1·6	22	2·9	33	4·2	44	5·4	55	6·7
1	0·5	12	1·8	23	3·0	34	4·3	45	5·5	56	6·8
2	0·6	13	1·9	24	3·1	35	4·4	46	5·6	57	6·9
3	0·7	14	2·0	25	3·3	36	4·5	47	5·8	58	7·0
4	0·8	15	2·1	26	3·4	37	4·6	48	5·9	59	7·1
5	1·0	16	2·2	27	3·5	38	4·7	49	6·0	60	7·2
6	1·1	17	2·3	28	3·6	39	4·8	50	6·1	61	7·4
7	1·2	18	2·4	29	3·7	40	5·0	51	6·2	62	7·5
8	1·3	19	2·6	30	3·8	41	5·1	52	6·3	63	7·6
9	1·4	20	2·7	31	3·9	42	5·2	53	6·4	64	7·7
10	1·5	21	2·8	32	4·0	43	5·3	54	6·6	65	7·8

In practice it is too laborious to measure wing margins with a map wheel, but the six categories already described (p. 292) are quickly diagnosed and may be used in conjunction with Table III. Table IV shows the mean and root mean fray per cent. corresponding to flies diagnosed by Mrs. Zieskowicz in categories 1 to 6. The mean age of flies so diagnosed is also given, together with the age which would have been deduced from Table III, which assumes a straight regression line. It will be seen that the actual and deduced ages agree fairly well, especially at the middle values likely to be found in samples.

TABLE IV.

Category.	Mean fray %.	Root mean fray %.	Age.	Deduced age.
1	1	1·0	9	5
2	4	2·0	15	14
3	9	3·0	25	23
4	19	4·4	33	35
5	30	5·5	44	45
6	47	6·9	48	57

By sticking a pin into a list of serial numbers, four random samples of 30 males each were then selected from the total. The result of this appears in Table V, which shows that the mean age of a sample of 30 can be deduced (within a day) by noting the number assigned to each category. The number of flies in each category is multiplied by the values of root mean fray given in Table IV, and the probable mean of the root mean fray is thus obtained, from which is read off the probable mean age from Table III.

As far as they go, these results look very promising. The method has been applied to numerous samples of both *G. morsitans* and *G. swynnertoni* in their natural environments, and gives broadly reasonable results, in that mean ages found are mostly from 20 to 30 days. The mean lives would be somewhat longer, in so far

TABLE V.

Category.	Root mean fray (probable).	Sample: 1	2	3	4
		Age: 17·2	17·3	27·9	29·4
1	1·0	11	9	5	2
2	2·0	10	9	3	6
3	3·0	3	7	12	9
4	4·4	3	4	4	7
5	5·5	1	0	1	2
6	6·9	2	1	5	4
Probable root mean fray		2·4	2·4	3·5	3·7
Deduced age		18	18	27	29

as not all the flies die at random, but some die of old age (Jackson, 1944). However, there are anomalies, as when *G. morsitans* introduced into the habitat of *G. swynnertoni* appears to live as long in the hot weather as in the cool, and to live on the whole somewhat longer than the native species. It must therefore be emphasised that, until we know more about the subject, the method must be used with caution. In particular, we need to discover whether as suggested above male flies are less active in the first two or three weeks of life, and whether constant results are obtained from place to place and from season to season. It may be that flies live faster in hot weather, wear out their wings more rapidly, and so appear, on this basis, older than they really are. Finally, it is desirable to find what differences there may be between different species. It is already known that *G. palpalis*, Robineau-Desvoidy, does not fray in the same sort of way as does *G. morsitans*.

Not many females were recovered after the first few days, but it was obvious that they wear out their wings less rapidly than do the males. Thus of females over 20 days old, the percentage frayings were: 24 days, 3, 4 and 10 per cent.; 25 days, 7 per cent.; 28 days, 6 and 13 per cent.; 35 days, 9 per cent.; 37 days, 9 per cent.; 45 days, 26 per cent.; 53 days, 14 and 22 per cent.; 61 days, 30 per cent. Reference to Table I shows that these are only about half the corresponding values for the males. It is believed that females, especially in later life, are relatively very inactive, and not only when man is the bait, which accounts for their wearing out their wings more slowly.

(*d*) *Dispersal.*

Data on dispersal of males are given in the last column of Table I. It was not possible to make the " spiral " fly-round big enough to include all the far-ranging flies, but the results are nevertheless interesting. On sections 12 and 13, 1,800 and 1,950 yards from the centre, the first flies were caught on day 17; on section 14, 2,100 yards from the centre, the first fly was caught on day 37. It seems unlikely that many more flies would have been caught on a large spiral in the first 20 or 30 days. During the first four weeks the means of the daily averages in Table I may therefore be taken as giving the approximate average nett distance travelled in one direction from the release site: they are 365 yards in week 1, 484 yards in week 2, 772 yards in week 3 and 941 yards in week 4.

With complete dispersal—equal densities on all sectors of the " spiral "—the mean found would be 1,450 yards, which is closely approached only in the ninth week. The mean for all male flies in the Table is 808 yards, which should be increased somewhat to allow for flies passing outside the " spiral ".

The females are too few to allow estimates of their dispersal.

The Reproductive Cycle.

Vanderplank (1944) showed that *G. morsitans* and *G. swynnertoni* in the laboratory mate at random with each other, and it has since been proved that this cross-mating occurs at random in the field (Jackson, 1945b). In spite of interference by *G. swynnertoni*, a considerable second generation of *G. morsitans* appeared in the present experiment, doubtless because the young colony immediately about the release site was not in the true haunt of the indigenous species.

A few dissections of female *G. morsitans* of the parental generation were done by Mr. W. H. Potts. On day 18 $\pm$ 1 from the emergence date, he dissected three females. Of these, two were fully inseminated, but with uterus empty and a partly developed egg in the left ovary, the right ovary undeveloped. This implies that the first egg, from the right ovary, had been aborted owing to lack of fertilisation. These females had probably mated with *G. swynnertoni*. The third fly on this day was fully inseminated, with a well-developed, white lobed, third stage larva in the uterus, a mature egg in the left ovary, and the right ovary undeveloped. On day 20 $\pm$ 1, a fourth female was dissected and was found to be in similar condition to the third fly just described.

Both of these last two females would have been expected to deposit their larvae in another two or three days. Median screen temperature* at Shinyanga (three miles from the release site) for days 1 to 19 was 22·7° C. The reproductive cycle in these two females was therefore very well up to time, and there is little doubt that they had been living approximately at the temperature measured in the screen, and not in some cooler ecoclimate of their own choice.

The first teneral flies of the second generation were taken on the " spiral " round on day 53; both were females. They were dissected by Mr. Potts, who from the development of the right ovaries formed the opinion that they were about 36 hours old. As the " spiral " round is done in the morning, it is likely that they emerged in the afternoon or evening of day 51. According to Jack (1939), the first larva is dropped at about day 19 at 24° C., and at the same temperature the pupal period is 31 days for females, so that 50 days is occupied from the emergence of the parent to the emergence of her first offspring, if that is a female.

From Jack's figure 16, page 105, a table was constructed, showing the fraction of the pupal period covered in one day at various temperatures and for each sex. From this table it was calculated that the two females in question had probably pupated on day 19, provided that the pupae experienced the median temperatures recorded in the screen. This agrees fairly well with the result of dissection of the parental females, thus showing that the soil temperatures experienced by the pupae were also approximately those measured in the screen.

On day 56 the first teneral male was captured. Supposing that, like the females, it had emerged two days before (day 54), it was calculated that it probably pupated on day 22. Bearing in mind the error of plus or minus one day, and that the fly may have been at large for more than two days, this result agrees with those preceding. Non-teneral flies of the second generation began to appear from day 60, so that the foregoing teneral flies were not exceptionally early.

The next teneral female was caught on day 63, and the next male on day 65, respectively 10 and 9 days after the first ones. According to Jack (*loc. cit.*), the period between larvae at 24° C. is 11 days, whereas median temperature from day 21 to day 32 was only 22·3° C. The above periods are therefore distinctly short; they do, however, suggest once more that the females in nature are not living in a cooler ecoclimate.

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* At this season, the median is close to the mean.

Thereafter teneral females were caught on days 69 and 73, and teneral males on days 72, 73, 74, 79, 80 and 86. Though there is a suggestion that the males occurred in "bursts", the intervals between them seem too short to indicate interlarval periods at the temperatures obtaining during embryonic life. It is, however, worth remarking that both the females on day 69 and the male on day 72 had extremely small wing veins, and may have been aborted a little before the proper time.

Not too much attention should be paid to the departures from expectation in the dates of the later teneral males captured, because a fly may remain teneral for several days after emergence. The evidence from the early flies is, however, strongly in favour of the conclusion that screen temperatures at this season represent very closely the temperatures that the flies and pupae are experiencing in nature.

Acknowledgement.

I am very much indebted to Mr. W. H. Potts for giving his time and lending his considerable experience to the investigation of the reproductive cycle studied in this experiment.

Summary.

A generation of *Glossina morsitans* was artificially isolated by allowing emergence for three days in the habitat of *G. swynnertoni* and *G. pallidipes*.

Most teneral flies (with chitin unhardened before their first meal) were active on day 2 to 4 from emergence. The non-teneral flies first appeared in numbers when a week old. It is possible that they were somewhat inactive while still fairly young, that is, up to two or three weeks, but this was not proved. They are definitely inactive between the first and second meals. The females, on the other hand, are much more active in the first three weeks of life than later on.

The teneral males contained about 12 mg. water, which was increased after several meals to a maximum of about 18 mg. by day 17. Fat started at a mean of $1\frac{1}{2}$ mg., declining to 1 mg. at the first meal, then rising to about 3 mg. at day 17, after which there was no further increase. Residual weight behaved like the water, except that it was relatively very low in teneral flies. The hungry flies which reappear after the first meal have also a relatively low residual weight.

In this experiment there was no evidence that smaller flies were at a disadvantage, as has been suspected from other work.

With reservations concerned with differences in place and time, the mean age of samples of male flies can be accurately deduced from the wear on the trailing margin of the wing. The females do not wear out their wings so quickly.

Males dispersed, in any one direction, to a mean perpendicular distance of 365 yards in a week, 484 yards in two weeks, 772 yards in three weeks, and 941 yards in four weeks.

In spite of undoubted interference by *G. swynnertoni*, a considerable second generation appeared.

The females and pupae in nature experienced temperatures approximating to those obtained in a screen at a standard meteorological station; they did not live in specially cool ecoclimates.

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THE MOSQUITOES OF BWAMBA COUNTY, UGANDA.

V.—The vertical Distribution and Biting-Cycle of Mosquitoes in Rain-Forest, with further Observations on Microclimate.

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(Plates V and VI.)

Since 1937 field investigations on yellow fever have been carried out in Bwamba County—a small heavily-forested area lying between the Ruwenzori Mountains and the Semliki River on the Uganda-Congo border. During 1941 yellow fever virus was isolated from a human case and from two lots of wild-caught *Aëdes* (*Stegomyia*) *simpsoni*, Theo., as reported by Mahaffy and others (1942). Following these discoveries entomological work in Bwamba was intensified and investigations are still in progress.

In June, 1942, virus was again isolated from *A. simpsoni*, which is a species frequenting banana and coffee plantations and maize fields in the inhabited areas. As an effective mass-vaccination of the entire population of Bwamba had been completed about 11 months previously, it seemed almost certain that the mosquitoes concerned had derived their infection from wild animals. Protection tests carried out on the blood of numerous animals from Bwamba revealed a high incidence of immunity to yellow fever in monkeys only, the many other groups studied being completely negative. Subsequent investigations on animals, therefore, were almost entirely confined to the collection of blood-samples from wild monkeys. The results of this work (Haddow, *et. al.*, in press) showed that all the species of monkeys known to inhabit the lowland forests are involved, the general immunity rate in the first 150 specimens being 61 per cent. The main focus of monkey infection was found to be the uninhabited Semliki Forest, where the lowland colobus monkey (*Colobus polykomos uellensis*, Matschie) seems to play a major part in the maintenance of the disease. While this monkey is probably the principal species implicated in the forest areas, its avoidance of inhabited and cultivated districts indicates that it is not likely to pass on infection to *A. simpsoni*, the local vector of human yellow fever. This rôle is probably filled by the redtail monkey (*Cercopithecus nictitans mpangae*, Matschie) which occurs both in the uninhabited forest and in bush and second-growth in the inhabited areas. This species, which shows a high incidence of immunity to yellow fever, is a notorious raider of banana plantations and maize fields, where *A. simpsoni* abounds.

There was thus evidence of the existence in Bwamba of a man-to-man yellow fever cycle with *A. simpsoni* as vector and of a monkey-to-monkey cycle in the forests, in no way dependent on the presence of human infection. Indeed, it may be stated that in Bwamba yellow fever is essentially a disease of monkeys, which is occasionally introduced into the areas inhabited by man. As *A. simpsoni* is not a sylvan species, it was realised that the monkey disease must be transmitted by some other vector, the most likely being a forest-dwelling mosquito. Attention was therefore turned to the Semliki Forest, which has been described in detail elsewhere (Haddow, 1945a) in an attempt to isolate virus from sylvan mosquitoes in uninhabited areas. During part of 1942 and the whole of 1943, catches were made in various forested districts, 53,000 mosquitoes being taken, of which over 46,000 were sent to Entebbe for the inoculation of rhesus monkeys and mice. During this period analysis by localities showed that the incidence of immunity in

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monkeys varied but little from one lowland area to another. It therefore seemed rational to concentrate on a single small forest district for mosquito work. The area finally chosen—Mongiro—is occupied by a dense strip of primary rain-forest and is inhabited by a remarkably large and varied monkey population. Nine species are known to occur at Mongiro, and the total population is estimated at not less than 400 in a single square mile of forest. This is an extremely high figure, far surpassing that for other parts of the Semliki Forest, where a reasonable estimate might be 50-100 monkeys per square mile.

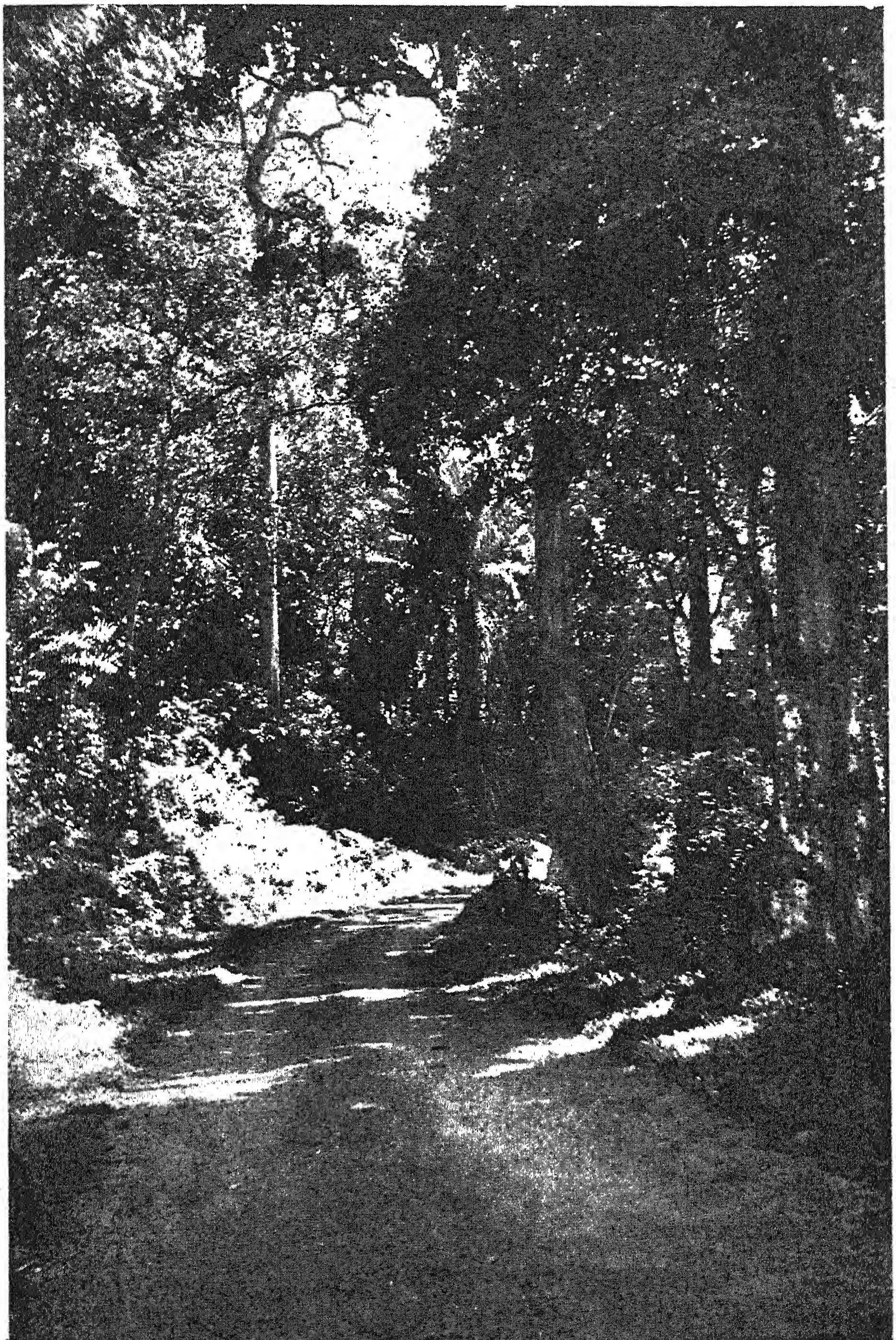
Large-scale catches were begun at Mongiro in January, 1944, the methods employed being identical to those described in a previous communication (Haddow, 1945b). In April yellow fever virus was isolated from a mixed lot of 80 *Aëdes*, belonging to 12 species. This isolation and the previous one in 1942 will be the subject of a separate communication (Smithburn & Haddow, in preparation), but it is necessary here to comment briefly on the various mosquitoes included in the infected lot. They were:—

Aëdes (*Stegomyia*) *apicoargenteus*, Theo.
A. (*S.*) *de-boeri* subsp. *de-meilloni*, Edw.
A. (*S.*) *africanus*, Theo.
A. (*Aëdimorphus*) *haworthi*, Edw.
A. (*A.*) *argenteopunctatus*, Theo.
A. (*A.*) *mutilus*, Edw.
A. (*A.*) sp. n., near *abnormalis*, Theo.
A. (*A.*) *cumminsi*, Theo.
A. (*A.*) *lamborni*, Edw.
A. (*A.*) *natronius*, Edw.
A. (*Banksinella*) *palpalis*, Newst.
A. (*B.*) *taeniarostris*, Theo.

(In the tables these species have been marked with asterisks for easy reference.)

Though it was not possible to tell from which species the virus was isolated, it is apparent that most of them can be eliminated from general epidemiological considerations in view of scarcity or of restricted distribution. Such are *A. de-boeri* subsp. *de-meilloni*, *A. haworthi*, *A. mutilus*, the new species of the *A. abnormalis* group, *A. lamborni*, *A. natronius*, *A. palpalis* and *A. taeniarostris*. Of the remainder, *A. argenteopunctatus* and *A. cumminsi* have a wide range, but have not yet been tested in the laboratory as vectors of yellow fever. *A. apicoargenteus* has a wide forest distribution, but experiments by Bauer (1928) indicate that it neither transmits nor maintains the virus—though it is felt that this work must be repeated with strains from different localities before the result is considered final. *A. africanus* has a wide forest range and has been shown to be an efficient transmitter in the laboratory (Philip, 1929). Thus, with the possible exception of *A. argenteopunctatus* and *A. cumminsi*, whose potentialities as vectors are unknown, *A. africanus* appears to be the most suspect species of the twelve.

Work in Colombia (Bugher & others, 1944, and Bates, 1944) has shown that the principal vector of yellow fever in that region (*Haemagogus capricornii*, Lutz) is essentially arboreal, reaching its highest concentration and main biting-activity in the forest canopy, a form of behaviour recently designated "acrodendrophily" by Garnham and others (1946). Now the monkey fauna of Bwamba includes two species (*Cercocebus albigena johnstoni* (Lydekker) and *Colobus polykomos uellensis*, Matschie) which rarely descend to the ground but which show a high incidence of immunity to yellow fever. It therefore seemed reasonable to conclude that a vector with arboreal habits must play a large part in the transmission of animal yellow fever in Bwamba, as in Colombia. An investigation of the arboreal mosquito fauna was clearly necessary, mainly to determine whether any of the 12 species in the infected lot occurred in the forest canopy in large numbers. It



The Bwamba road in the forest at Mongiro. The figures on the right give some idea of the height of the canopy at this point. They are seated at the foot of a 'kitoko' (*Cola cordifolia* (Cav.) R. Br.).

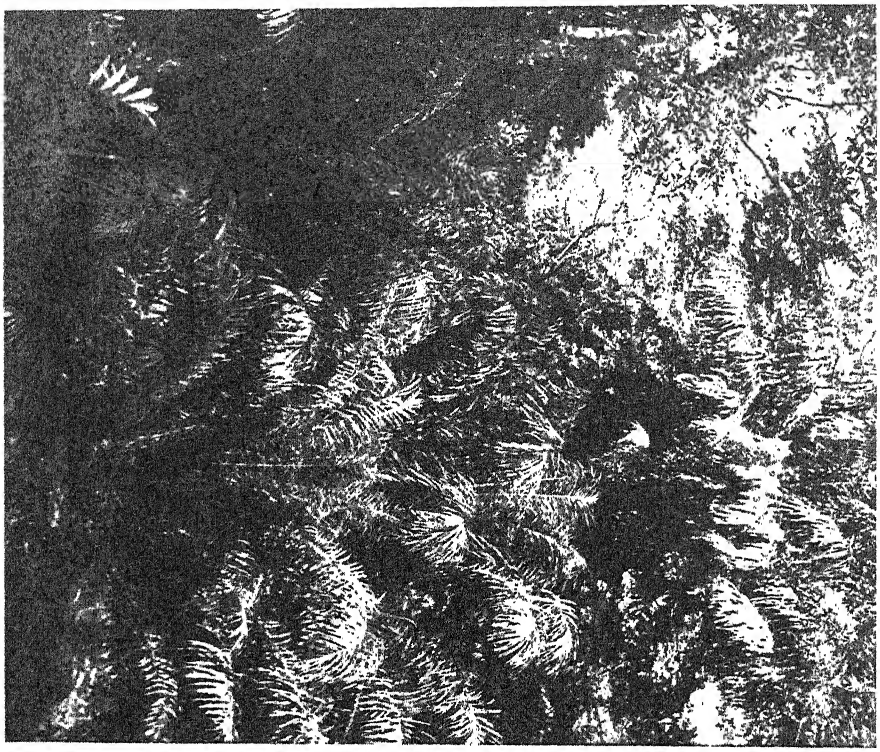


Fig. 1

Fig. 2

was felt that if any of these mosquitoes showed definite arboreal tendencies it might be regarded as probably involved in the local transmission of monkey yellow fever, even if virus were not isolated during the course of the investigation.

Series of 24-hour catches made simultaneously at different levels above ground were therefore begun, the areas chosen being Mongiro itself and Mamirimiri, an adjacent belt of primary rain-forest of a rather different type. Yellow fever virus was not again isolated during 1944 and, after the completion of the 24-hour catches in July, entomological work was temporarily suspended, over 35,000 mosquitoes having been collected at Mongiro and Mamirimiri and in some adjacent forest areas since the beginning of the year. In the course of the work six strains of Rift Valley Fever virus were isolated from *Aëdes* and *Eretmapodites* spp. taken at ground level at Mongiro—a subject which will be discussed further in a separate communication (Smithburn & others, in preparation).

The Forest at Mongiro and Mamirimiri.

The forest area at Mongiro lies at an altitude of about 2,500 feet on the eastern edge of the Semliki Forest. To the west it is continuous with the main forest, which may be considered as a part of the great Ituri Forest, but to the south it is bounded by the large grassy clearing of Bamaga and to the north by the hot sulphur springs of Mbuga and Niansimbi and by the open Semliki Plains which stretch away to the southern shores of Lake Albert. To the east the Mongiro area is limited abruptly by the Ruwenzori foothills, which here rise steeply to a height of about 8,000 feet. On the foothills the dense forest of the lowlands is replaced by high evergreen scrub and *Euphorbia calycina*, N. E. Br., with a small belt of mountain forest in the upper levels.

The Mongiro forest (Pl. V) is of a very mixed type. The soil is black and rich and is threaded by numerous streamlets and runnels which flow all year round. The marshy forest floor supports a dense growth of large-leaved Zingiberaceae and Marantaceae (notably *Marantochloa* sp.) which form a good harbourage for resting mosquitoes. The dominant tree is the "munyamaizi" (*Mitragyna stipulosa* (DC.), O. Ktze.), a marsh-loving species with large leaves which form a dense crown. There is a certain amount of African ironwood (*Cynometra alexandri*, C. H. Wright), African teak or "muvule" (*Chlorophora excelsa* (Welw.), Benth. & Hook. f.), Uganda mahogany (*Khaya anthotheca* (Welw.), C.DC.), "bolwe" (*Celtis soyauxii*, Engl.), upas tree or "kesuba" (*Antiaris toxicaria* (Rumph. ex Pers.), Lesch.), and stool-wood (*Alstonia congensis*, Engl.), while giant figs, notably the "kiloko" (*Ficus capensis*, Thunb.) are abundant. Many of the larger trees in this humid forest are almost hidden by lianas, climbing rattans, rubber vines and parasitic "strangler" figs. Epiphytic ferns and orchids are common on the upper branches. While the general canopy is not high (only about 50-80 feet) some of the timber trees reach heights of over 100 feet and many of the lower specimens have enormously thick heavily-buttressed trunks. There is considerable variety among the understorey trees, which include the archaic screw-pine (*Pandanus chiliocarpus*, Stapf.), whose enormous axils are favourite breeding-places for certain mosquitoes—particularly *Uranotaenia* spp. Throughout the area the oil-palm (*Elaeis guineënsis*, Jacq.) is very abundant, fruiting irregularly through the whole year (Pl. VI, fig. 1). It is largely on account of this prolific yield of oil-nuts that such a huge monkey population is able to thrive in such a small area.

The Bwamba road traverses this forest strip, but human dwellings are scarce around Mongiro. The nearest huts are about half-a-mile from the forest edge and the entire population of the area is only about ten individuals. So far as is known, all of these have been vaccinated against yellow fever. The district is regarded with superstitious awe by the natives, as the Niansimbi hot spring was formerly a place of child sacrifice, while the inhabitants of a once-thriving village in the

Bamaga clearing were almost completely wiped out by a sudden epidemic which occurred some years ago. The abundance and variety of big game at Mongiro—notably elephant and buffalo—also serves as a deterrent to settlers.

The general picture is thus of a partly-isolated strip of dense lowland rain-forest, usually very warm and humid, of a distinctly "tropical" type, inhabited by large numbers of monkeys and other wild animals and with a huge and varied mosquito-fauna.

The second catching-area, Mamirimiri, lies south of the Bamaga clearing and about half-a-mile from the southern edge of the Mongiro forest belt. The soil here is drier and, though the trees are mainly of the same species as at Mongiro, *C. alexandri* is dominant. In addition to those mentioned above, the flame-tree (*Spathodea campanulata,* Beauv.), "nsambya" (*Markhamia platycalyx* (Bak.), Sprague) and a coral-tree (*Erythrina excelsa,* Baker) are common. The oil-palm, though common at Mamirimiri, is scarcer than at Mongiro and consequently monkeys are less abundant. In general the canopy is higher, in some places occupying a zone 70-90 feet above ground. Surrounding this rather dry forest area, and in sharp contrast, is an extensive tract of swamp with a remarkably dense and tangled growth of *Pandanus,* canes, rattans, etc. In this swamp oil-palms grow in large clumps and the wild-date (*Phoenix reclinata,* Jacq.) is particularly common.

In considering rain-forest it is essential to remember that it consists of horizontal strata of vegetation, each characterised by its particular flora and each with its specialised fauna of birds, insects, etc. The importance of this point will be made apparent below. The main zones at Mongiro and Mamirimiri may be described as follows:—

1. Undergrowth of a very mixed type, reaching heights of 3-10 feet.
2. A light, discontinuous zone of young trees, arrested in their growth by want of light and space, with some small understorey trees, at about 10-15 feet.
3. The main foliage zone of the understorey, with its numerous definitive species, at 30-50 feet. The crowns of the larger oil-palms lie mainly in this stratum.
4. The main canopy, usually beginning at about 50 feet and nowhere exceeding 100 feet.
5. The zone of giant trees, which may be about 30 per square mile. The crowns of these trees rise clear above the main canopy and in many cases their first branches may be as much as 80-90 feet above ground. In general these trees are 120-130 feet high, and so far only one specimen exceeding 150 feet has been noted in Bwamba.

Methods.

At Mongiro three platforms were built in the trees at heights of 16, 31 and 54 feet respectively, each capable of supporting a bait of four boys. Following the advice of Dr. J. C. Bugher, short prefabricated ladders (5-8 feet long) were used, these being nailed to the trees one above the other till the required height was attained. The platforms themselves were built of local green timber. The 16-foot platform was built in an understorey tree with large leaves (*Macaranga schweinfurthii,* Pax). It was above the highest undergrowth, but below the foliage of the understorey proper. The 31-foot platform was placed in the lower branches of an ironwood (*C. alexandri*), in the understorey foliage, at a level where the fronds of the oil-palms form a considerable proportion of the vegetation. The 54-foot platform was in the crown of a "munyamaizi" (*M. stipulosa*) in the main forest canopy and above the heads of all but the largest palms. The three platforms were placed

at the corners of a triangle with sides about 30 yards long. In the centre a station for a ground-level unit was selected. While it would have been preferable to build all the stations at different heights in a single tree, careful search failed to reveal a suitable tree in the area concerned.

At Mamirimiri four similar platforms were built. The first, at 22 feet, was placed in the lower branches of a coral-tree (*E. excelsa*) just below the main understorey foliage. The second was built at 44 feet in the same tree, towards the upper limit of the understorey. The third platform, 58 feet high, occupied a central position in the foliage of a "kitoko" (*Cola cordifolia* (Cav.), R. Br.) which was almost completely enveloped by an unidentified parasitic fig. This platform was in a very dense part of the main canopy. The last, at 82 feet (Pl. VI, fig. 2), was built in a large stool-wood (*A. congensis*). The crown of this tree, about 100 feet above ground-level, rose somewhat beyond the upper level of the main canopy, but its branches mingled with the upper foliage of the canopy. Again the platforms occupied the corners of a triangle, the sides being about 50 yards long. In the centre a station for a ground-level unit was selected. Throughout the work of building care was taken not to disturb the vegetation more than was absolutely necessary.

At Mongiro a series of 10 continuous 24-hour catches was carried out, using all the platforms and the ground station simultaneously, and an exactly similar series was carried out at Mamirimiri. The work was superintended by the writers in turn, so that the catches were under almost continuous European supervision both by day and by night. During the work four catchers were employed at each level. As it was necessary to complete the investigation rapidly, the catches were made in non-stop groups of 2-5 consecutive 24-hour periods. To avoid fatigue among the catchers, eight were assigned to each platform, one boy changing over each hour. Thus each catcher worked and rested for 4-hour periods alternately. This system also tended to minimise the effects of differences in individual attractiveness. It would have been preferable to have each worker move in succession through each catching-station, but it was found that the time taken in moving from one platform to another tended to interfere with the continuity of the catch. The methods were thus very similar to those previously used in Bwamba in studying the vertical distribution of mosquitoes in a banana plantation (Haddow, 1945c).

The mosquitoes were caught singly in short test-tubes, lightly plugged with cotton. At the end of each hour a bag, numbered with the time and station, was sent up to each platform and the bag containing the previous hour's catch was brought down. Where Africans are employed as catchers it is most necessary that some such simple scheme should be used, or confusion will inevitably follow. After sorting and recording in the field laboratory, the mosquitoes were transferred to Barraud cages for transport to Entebbe, where they were used for the inoculation of rhesus monkeys and mice.

These 20 catches were made between 30th May and 8th July, towards the close of the main rainy reason of 1944. At the end of this period work on microclimate on the platforms at Mongiro and Mamirimiri was carried out by one of the writers (A.J.H.). The technique will be described below in the appropriate section.

At the beginning of 1945 a period of exceptionally dry weather occurred. From the end of December, 1944, till the end of March, 1945, only a few light local showers occurred and it is believed that this was the driest spell in Bwamba for 35 years. The forest floor was almost dry in most places and was carpeted with withered leaves. The canopy foliage became very scanty and numerous trees (even well within the main forest) were seen to have brown "autumn" leaves, a most exceptional occurrence in rain-forest. From the point of view of yellow fever epidemiology it was essential to determine whether any of the arboreal

mosquitoes could survive such a period in the adult state in numbers large enough to be of importance. One of the writers (A.J.H.), therefore, carried out exactly similar series of catches at Mongiro and Mamirimiri, the period covered by the 20 catches being 9th February to 11th March.

It may be mentioned that in the course of the investigation information was gained about the habits of certain arboreal TABANIDAE. These observations, and the results of subsequent routine catches on tree-platforms, will be the subject of separate communications, the present paper being confined to the 40 catches in the critical comparative series.

The biting-cycle of Bwamba mosquitoes has been discussed at length in a previous paper, to which frequent reference will be made below (Haddow, 1945b). The subject will be dealt with rather briefly here, mainly with regard to cases where the results differ from those previously obtained. As in this earlier work, it has been found best in almost all cases to divide the 24 hours into six periods of four hours each, beginning at sunrise, which may be taken as about 06 hours L.M.T. These 4-hour periods agree well with the successive climatic phases of the day and night. Their main characteristics may be summarised as follows:—

Period 1. 06-10 hours.—Temperature relatively very low and saturation deficiency very low. Relative humidity very high.

Period 2. 10-14 hours.—Temperature and saturation deficiency at their maxima. Relative humidity at its minimum.

Period 3. 14-18 hours.—Temperature high, saturation deficiency falling and relative humidity rising.

Period 4. 18-22 hours.—Temperature still fairly high, saturation deficiency very low and relative humidity very high.

Period 5. 22-02 hours.—Temperature low, saturation deficiency very low and relative humidity very high.

Period 6. 02-06 hours.—Temperature and saturation deficiency at their minima. Relative humidity at its maximum.

It should be noted that no two of these periods have the same characteristics. Points of special importance are that in Period 4 fairly high temperature is associated with very low saturation deficiency and very high relative humidity, and that during the night temperature falls steadily while saturation deficiency and relative humidity change but little (figs. 10 and 11).

Analysis of the detailed results has not shown significant differences between the biting-cycles at different levels, nor between the cycles at Mongiro and Mamirimiri. It is thus possible to combine the results from all levels and both areas in order to increase the size of the various samples.

In the case of vertical distribution it is necessary to consider the two areas and the two seasons separately. The symmetrical graphs showing the distribution of the important species are of a type widely used in marine biology for plotting the vertical distribution of planktonic organisms at different depths, but so far little employed in entomological work.

Throughout the investigation one of the most interesting observations was the marked consistency of behaviour in a given species, both with regard to the time and level at which its greatest activity might be expected. Finally, the weather being known, fairly accurate prediction of the size and nature of the catch became possible—a fact which has aided greatly in subsequent routine platform catches when the maximum yield of certain species is desired.

List of Species.

It is convenient to give at this point a complete list of the species taken, to allow the use of abbreviated names in the subsequent text and tables:—

Anopheles (*Anopheles*) *paludis*, Theo.
A. (*A.*) *obscurus*, Grünb.
A. (*A.*) *implexus*, Theo.
A. (*Myzomyia*) *funestus*, Giles
A. (*M.*) *keniensis*, Evans
A. (*M.*) *gambiae*, Giles
A. (*M.*) *pharoensis*, Theo.
Uranotaenia sp. indet., near *annulata*, Theo.
U. ornata subsp. *musarum*, Edw.
U. fusca, Theo.
Ficalbia (*Mimomyia*) *plumosa*, Theo.
Ficalbia ? sp. n., near *mediolineata*, Theo.
Taeniorhynchus (*Coquillettidia*) *maculipennis*, Theo.
T. (*C.*) *fuscopennatus*, Theo.
T. (*C.*) *aurites*, Theo.
T. (*C.*) *aureus*, Edw.
T. (*C.*) *microannulatus*, Theo.
T. (*Mansonioides*) *africanus*, Theo.
T. (*M.*) *uniformis*, Theo.
Aëdes (*Mucidus*) *grahami*, Theo.
A. (*Finlaya*) *longipalpis*, Grünb.
A. (*F.*) *ingrami*, Edw.
A. (*Stegomyia*) *apicoargenteus*, Theo.*
A. (*S.*) *fraseri*, Edw.
A. (*S.*) *de-boeri* subsp. *de-meilloni*, Edw.*
A. (*S.*) *africanus*, Theo.*
A. (*Aëdimorphus*) *haworthi*, Edw.*
A. (*A.*) *mutilus*, Edw.*
A. (*A.*) *domesticus*, Theo.
A. (*A.*) *tarsalis*, Newst. group.
A. (*A.*) sp. n., near *abnormalis*, Theo.*
A. (*A.*) *lamborni*, Edw.*
A. (*A.*) *cumminsi*, Theo.*
A. (*A.*) *natronius*, Edw.*
A. (*Banksinella*) *circumluteolus*, Theo.
A. (*B.*) *palpalis*, Newst.*
Eretmapodites chrysogaster, Graham
E. inornatus, Newst. group.
E. ferox, Haddow
Culex (*Lutzia*) *tigripes*, Grp. & C.
Culex spp. indet.

Some comments on this list are necessary:—

The various *Uranotaenia* and *Ficalbia* spp. are not known to bite man. It is probable that their occurrence in the catches was fortuitous and, though listed in the various tables, they will not be discussed further in the text. The new species of *Ficalbia*, which resembles *F.* (*Etorleptiomyia*) *mediolineata*, Theo., is at present under study by Mrs. Ellinor C. van Someren, of the Medical Research Laboratory, Nairobi.

At Mongiro and Mamirimiri the *A. tarsalis* group is represented by roughly equal numbers of *A.* (*A.*) *tarsalis*, Newst., and *A.* (*A.*) *albocephalus*, Theo. As

the writers do not believe that the females of these species can always be distinguished reliably—certainly not in life—it has seemed best to treat them collectively. The new species of the *A. abnormalis* group is at present under study by Mrs. van Someren.

In both areas the *E. inornatus* group is represented by *E. inornatus*, Newst., and *E. penicillatus*, Edw. The only reliable distinction between the females appears to be the form of the claws of the foreleg, a character which cannot be used in the case of live specimens. *E. ferox* is a recently-described species (Haddow, 1946), closely resembling *E. dracaenae*, Edw., and so far known only from Bwamba.

No attempt has been made to distinguish the small species of *Culex*. At least 17—some of them undescribed—are known to occur at Mongiro. Some of these are at present being studied by Mrs. van Someren.

The results of the catches may now be discussed:—

ANOPHELES.

A. paludis, *A. obscurus* and *A. keniensis* were too poorly represented in the catches to be worthy of comment. *A. implexus*, as in the previous catches in Bwamba, seemed to bite indifferently by day and by night.

It was interesting to find *A. funestus* biting in forest, though in small numbers, and to note that at Mongiro it was taken at all levels (Table I). It seems likely that the occurrence of this species in the Semliki Forest, where suitable breeding-waters are scarce, is due to immigration from outside—perhaps from the large swamps along the Semliki River where, in spite of the absence of man, it is quite abundant.

It is believed that *A. pharoensis* shows a tendency to wander far from its breeding-grounds and it seems probable that those taken in the present catches came from the large grassy swamps of the lower Semliki, far out on the open plains. Most of the specimens were taken on two nights at Mongiro, and it seems likely that at that time they were migrating across the forest. Sudden and short irruptions of this species have previously been noted in Bwamba.

The occurrence of *A. gambiae* in several parts of the uninhabited Semliki Forest, including the banks of the Semliki River at least six miles from the nearest habitation, has already been discussed at some length (Haddow, 1945a). In view of the major part played by this species in malaria transmission, the identification has been confirmed by the examination of larvae bred from females taken in the forest and by the dissection of wild-caught forest adults for examination of the male terminalia and female pharyngeal armature. The writers (all of whom have had experience of *A. gambiae* in infested urban areas) have never seen this usually domestic species in concentrations approaching those encountered at Mongiro and Mamirimiri, where over 30,000 (representing 93 per cent. of the total for all species) were taken in the 40 catches (Table II).

TABLE I.
The vertical distribution of mosquitoes at Mongiro and Mamirimiri.

Species	Mongiro								Mamirimiri									
	Rainy season, 1944				Dry season, 1945				Rainy season, 1944					Dry season, 1945				
	0′	16′	31′	54′	0′	16′	31′	54′	0′	22′	44′	58′	82′	0′	22′	44′	58′	82′
A. paludis	...	...	...	...	1	...	...	...	...	...	...	1	...	...	...	...	...	...
A. obscurus	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
A. implexus	2	...	...	...	...	...	...	...	6	...	...	...	...	2	...	...	...	...
A. funestus	6	2	2	3	1	...	1	1	4	5	...	...	...	1	2	...	...	3
A. keniensis	...	...	...	...	1	...	...	...	...	...	...	...	...	2	...	...	...	...
A. gambiae	6073	1907	1299	619	6154	1357	684	340	4955	802	215	167	155	4697	419	164	128	105
A. pharoensis	...	...	...	...	6	2	4	5	...	...	...	...	...	2	...	...	...	...
U. annulata group	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
U. ornata subsp. *musarum*	...	...	1	2	...	...	...	...	...	1	...	...	...	...	1	...	...	...
U. fusca	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...
F. plumosa	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
F. mediolineata group	1	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
T. maculipennis	...	...	...	...	...	...	...	...	1	...	...	...	...	3	1	...	...	...
T. fuscopennatus	2	1	4	3	1	1	...	...	1	...	1	2	3	1	3	1	...	...
T. aurites	...	...	...	...	...	...	1	...	...	...	...	...	1	...	...	...	...	...
T. aureus	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...
T. microannulatus	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1
T. africanus	22	11	15	21	4	...	...	2	10	2	3	9	7	8	3	1	1	3
T. uniformis	...	2	3	1	...	...	...	...	...	1	3	1	...	...	1	...	1	...
A. grahami	...	1	3	...	...	...	1	1	...	...	3	3	2	...	...	2	1	1
A. longipalpis	...	1	2	3	...	1	...	...	...	3	5	11	8	...	...	...	6	...
A. ingrami	3	...	1	...	...	...	...	...	1	1	1	...	2	...	...	...	...	1
*A. apicoargenteus**	5	37	32	6	...	...	2	1	4	14	55	33	12	1	1	...	2	...
A. fraseri	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
A. de-boeri subsp. *de-meilloni**	2	1	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
*A. africanus**	3	14	23	49	1	1	3	2	17	27	76	150	70	1	1	1	20	4
*A. haworthi**	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
*A. mutilus**	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
A. domesticus	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
A. tarsalis group	111	13	...	...	11	1	2	...	86	5	2	...	...	18	...	...	...	...
A. abnormalis group*	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...
*A. lamborni**	...	...	...	...	4	...	...	...	...	...	...	...	...	1	...	...	...	...
*A. cumminsi**	20	1	1	...	2	...	...	...	22	...	...	1	...	1	...	...	...	1
*A. natronius**	4	1	1	9	2	...	...	1	4	1	4	8	6	1	...	...	...	...
A. circumluteolus	73	3	...	...	17	...	1	...	53	6	...	1	...	13	...	1	...	...
*A. palpalis**	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
E. chrysogaster	12	...	...	...	...	...	...	...	1	...	...	...	...	1	...	...	...	...
E. inornatus group	1	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...
E. ferox	...	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...	...	...
C. tigripes	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1
Culex spp. indet.	17	14	17	13	173	66	51	53	23	13	40	30	55	56	18	28	37	42

TABLE II.

Total catches of the various species and groups at Mongiro and Mamirimiri.

Species	Mongiro		Mamirimiri		Grand total
	Rainy season, 1944	Dry season, 1945	Rainy season, 1944	Dry season, 1945	
A. paludis	...	1	1	...	2
A. obscurus	...	...	1	...	1
A. implexus	2	...	6	2	10
A. funestus	13	3	9	6	31
A. keniensis	...	1	...	2	3
A. gambiae	9,898	8,535	6,294	5,513	30,240
A. pharoensis	...	17	...	2	19
U. annulata group	1	...	...	...	1
U. ornata subsp. *musarum*	3	...	1	1	5
U. fusca	...	...	...	1	1
F. plumosa	1	...	...	...	1
F. mediolineata group	1	...	1	...	2
T. maculipennis	...	...	1	4	5
T. fuscopennatus	10	2	7	5	24
T. aurites	...	1	1	...	2
T. aureus	1	...	...	1	2
T. microannulatus	...	...	1	1	2
T. africanus	69	6	31	16	122
T. uniformis	6	...	5	2	13
A. grahami	4	2	8	4	18
A. longipalpis	6	1	27	6	40
A. ingrami	4	...	5	1	10
*A. apicoargenteus**	80	3	118	4	205
A. fraseri	1	...	...	...	1
A. de-boeri subsp. *de-meilloni** ...	3	...	1	...	4
*A. africanus**	89	7	340	27	463
*A. haworthi**	2	...	...	...	2
*A. mutilus**	2	...	...	...	2
A. domesticus	...	...	...	1	1
A. tarsalis group	124	14	93	18	249
A. abnormalis group*	...	1	...	...	1
*A. lamborni**	...	4	...	1	5
*A. cumminsi**	22	2	23	2	49
*A. natronius**	15	3	23	1	42
A. circumluteolus	76	18	60	14	168
*A. palpalis**	...	...	...	1	1
E. chrysogaster...	12	...	1	1	14
E. inornatus group	1	2	...	...	3
E. ferox...	...	3	...	...	3
C. tigripes	...	...	...	2	2
Culex spp. indet.	61	343	161	181	746

A. gambiae was not merely the commonest species—it was the commonest species at every level. It was taken at all stations on every day of the entire investigation (Table V). By night an observer could hear the *A. gambiae* flying round the ground-level units, and in the morning numbers up to 50 were counted on the windscreens of cars left standing overnight on the road at Mongiro. The readiness with which this species bites out-of-doors in the Bwamba forests, even during the day, contrasts strongly with its usual endophilic habits. It should be noted, however, that at Mongiro and Mamirimiri it can be taken in tents even

more readily than in the open. As a rule the spare members of the catching-squad slept outside, near a smoky fire, as within a tent the persistent attacks of this mosquito made rest impossible.

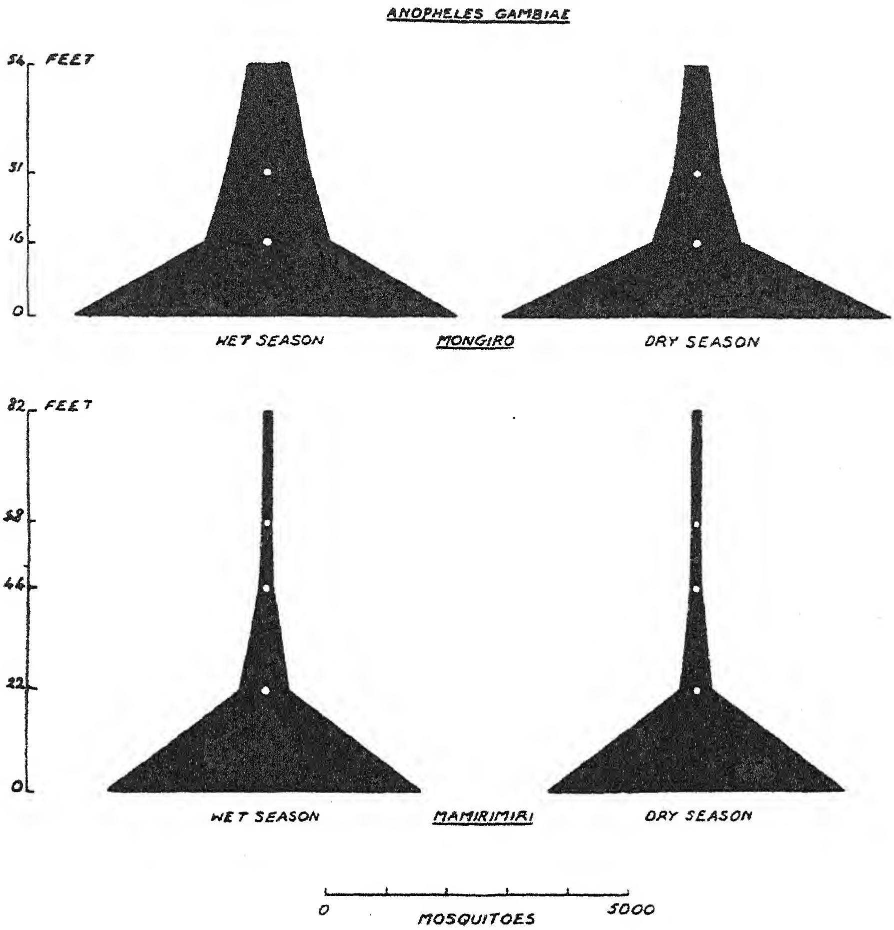


FIG. 1.—The vertical distribution of *Anopheles gambiae*.

It will be seen that *A. gambiae* bites mainly at ground-level, 72 per cent. of the total having been taken by the ground units (Table I and fig. 1) and that in each series the number decreases steadily with increasing altitude. It must be emphasised, however, that the numbers taken on the high platforms were considerable, as for instance 260 in 20 catches on the 82-foot platform at Mamirimiri and 959 on the 54-foot platform at Mongiro. The presence of this species in large numbers in the canopy of uninhabited rain-forest raises questions concerning its food in such habitats.

It will be seen that the vertical distribution of *A. gambiae* was essentially the same both in the wet and the dry season. In both areas a higher percentage was taken on the ground in the dry season and though the differences are too small to be considered statistically significant, this is probably a slight manifestation of the dry-season retreat to the optimum level shown more clearly by certain other

mosquitoes. The fact that the dry-season catches were only slightly smaller than those made during the rains is a purely local phenomenon, due to the partial drying-out of large grassy swamps which are normally unsuitable as breeding-waters for this species. In dry weather much of the swamp vegetation dies back, exposing large numbers of small muddy pools in the footprints of elephant, buffalo, etc. It may be mentioned here that we have never found *A. gambiae* larvae in Bwamba in what could be considered abnormal breeding-places—apart from the absence of human dwellings. Here as elsewhere sunlit puddles are the chosen habitat.

The biting-cycle (Table III) shows characteristics similar in general to results previously obtained in the Bwamba forests, the main biting-period being between

TABLE III.

The biting-cycle of mosquitoes at Mongiro and Mamirimiri, by 4-hour periods. All levels collectively.

Period (hours, L.M.T.)	06–10	10–14	14–18	18–22	22–02	02–06
A. paludis	...	...	...	1	...	1
A. obscurus	...	...	...	...	1	...
A. implexus	2	1	2	3	1	1
A. funestus	12	...	1	4	...	14
A. keniensis	2	...	...	...	...	1
A. gambiae	2,191	264	507	5,009	8,284	13,985
A. pharoensis	...	...	...	2	1	16
U. annulata group	...	...	...	...	...	1
U. ornata subsp. *musarum* ...	...	...	...	1	2	2
U. fusca	...	...	...	...	1	...
F. plumosa	...	...	...	1	...	...
F. mediolineata group	...	...	...	...	1	1
T. maculipennis	2	1	1	...	...	1
T. fuscopennatus	...	...	...	14	6	4
T. aurites	...	...	...	...	1	1
T. aureus	...	...	...	1	1	...
T. microannulatus	...	...	...	1	1	...
T. africanus	5	1	1	69	26	20
T. uniformis	1	...	...	6	3	3
A. grahami	...	...	...	4	10	4
A. longipalpis	9	19	12	...	...	...
A. ingrami	1	4	1	4	...	...
*A. apicoargenteus**	25	80	100	...	...	...
A. fraseri	...	1	...	...	...	...
A. de-boeri subsp. *de-meilloni** ...	2	...	2	...	...	...
*A. africanus**	33	18	30	318	39	25
*A. haworthi**	1	1	...	...	...	...
*A. mutilus**	1	1	...	...	...	...
A. domesticus	...	...	...	1	...	...
A. tarsalis group	114	45	47	26	7	10
A. abnormalis group*	...	...	...	1	...	...
*A. lamborni**	2	...	1	2	...	...
*A. cumminsi**	9	3	6	14	11	6
*A. natronius**	3	2	1	29	4	3
A. circumluteolus	32	23	63	34	7	9
*A. palpalis**	...	...	...	1	...	...
E. chrysogaster	4	...	9	1	...	...
E. inornatus group	1	...	2	...	...	...
E. ferox	2	1	...	...	...	...
C. tigripes	...	...	...	1	1	...
Culex spp. indet.	76	11	68	355	135	101

midnight and dawn. There is, however, one important difference. In previous work it was found that there was little difference between the catch from 22-02 hours and that from 02-06 hours. In the present series, however, the latter period showed a huge increase over the former (fig. 8). This result was noted consistently night after night both in the wet- and the dry-season catches. In view of the importance of *A. gambiae* and the large size of the sample, it has seemed worth while to quote the detailed hourly figures (Table IV and fig. 2) which show a fairly

TABLE IV.

The biting-cycle of *A. gambiae* and *A. africanus* at Mongiro and Mamirimiri by 1-hour periods. All levels collectively.

Period (hours L.M.T.)	*A. gambiae*	*A. africanus*
06–07	1,482	13
07–08	375	10
08–09	216	6
09–10	118	4
10–11	89	7
11–12	80	2
12–13	32	3
13–14	63	6
14–15	44	5
15–16	81	4
16–17	150	3
17–18	232	18
18–19	1,007	195
19–20	1,081	76
20–21	1,266	31
21–22	1,655	16
22–23	1,882	16
23–24	1,967	12
00–01	2,119	5
01–02	2,316	6
02–03	2,823	8
03–04	2,984	5
04–05	3,829	2
05–06	4,349	10

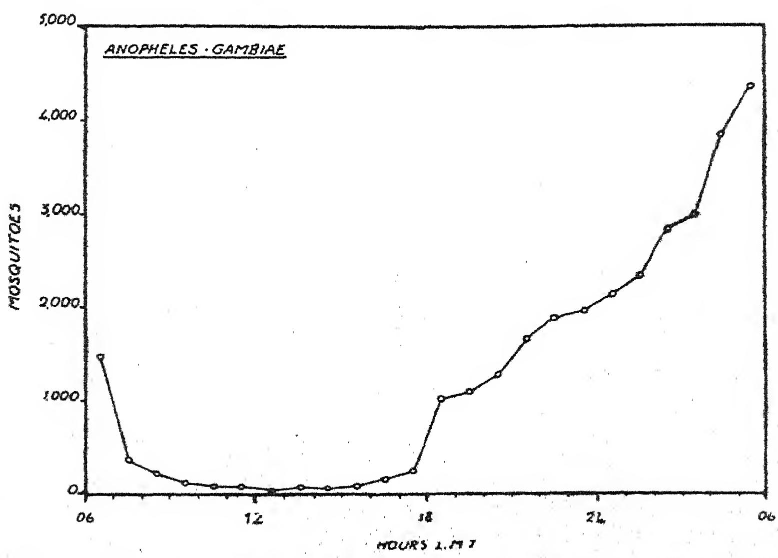


FIG. 2.—The biting-cycle of *Anopheles gambiae*—hourly totals for the entire series of 40 catches.

steady increase throughout the night. This observation leads to the belief that temperature may be among the most important of the microclimatic factors affecting the biting-cycle of this species, as it declines steadily throughout the night, while relative humidity shows a remarkably even " plateau " at almost 90 per cent. R.H. The fact that *A. gambiae* can regularly be taken biting in fair numbers by day in several parts of the Semliki Forest has already been discussed (Haddow, 1945b). This habit probably results from the equability of the forest microclimate which retains the low temperature and high humidity of the night far into the morning and which even at midday shows no sudden or pronounced fluctuations.

Taeniorhynchus.

Though so far no member of this genus has been incriminated as a vector of yellow fever in the field, one species (*T. africanus*) has been shown to be capable of transmitting under laboratory conditions (Philip, 1930). This mosquito is known to have a long flight-range and to bite freely both indoors and in the open (Kerr, 1933) and it has a very wide distribution (Edwards, 1941). It must consequently be regarded as a possible vector and other members of the genus—several of which attack man viciously in the Semliki Forest—must also be regarded with suspicion.

T. maculipennis, T. aurites, T. aureus and *T. microannulatus* were very poorly represented in the catches, but it will be noted that all of them were taken on tree-platforms (Table I). Little is known of their habits as they are all rather scarce in Bwamba with the exception of *T. maculipennis,* which is sometimes taken in large numbers in day-catches. The diurnal habits of this species have also been noted at Entebbe (Gillett, 1946).

T. fuscopennatus, though not abundant in the present catches, is a common mosquito in Bwamba. The sample is not adequate for discussion of the level preferred, but it will be seen that this species was taken at every station in both areas. *T. fuscopennatus* is essentially nocturnal in its biting-habits (Table III and fig. 8). The marked preference for the 18-22 hours period shown in the present catches is likely to be due to the small size of the sample as previous work in Bwamba, where much greater numbers were involved, showed this species biting actively throughout the night, only occasionally with a distinct peak of activity in the post-sunset period.

It was interesting to find *T. africanus* biting at all levels at Mongiro and Mamirimiri, the wet-season catches in both areas showing the highest numbers at the ground stations and in the main forest canopy. Of the total catch of 122, 43 (35 per cent.) were taken at heights of over 50 feet. It is concluded that this species occurs in the forest canopy in numbers large enough to be of importance. The numbers taken in the dry season were small, being equal to only 22 per cent. of the wet-season catch, but it appears that this suspect mosquito is to be found biting in the canopy throughout the year.

In considering the possible relationship of a given mosquito to yellow fever epidemiology, it is felt that importance attaches not only to the numbers taken but also to the consistency with which it appears in the catches. It is evident that a species which can be taken regularly day after day in one area is more likely to be of importance than one which suddenly appears in large numbers and then disappears—as is often the case with such mosquitoes as *Aëdes cumminsi.* In this connection it is interesting to note that *T. africanus* was taken on 29 of the 40 days of the investigation (Table V).

As in previous work in Bwamba, *T. uniformis* was much scarcer than *T. africanus,* but enough were taken to show that this species also bites in the trees. The biting-cycles of both these species agreed closely with previous results, being mainly nocturnal, with a pronounced peak of activity after sunset in the 18-22 hours period (Table III and fig. 8).

TABLE V.

The results of 40 catches at Mongiro and Mamirimiri, to show the numbers of days on which the various species and groups were taken. All levels collectively.

Species	Days																																							Tot.
A. gambiae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	40
Culex spp. indet. ...	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	39
A. tarsalis group ...	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	35
A. circumluteolus ...	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	34
*A. africanus**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	32
T. africanus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	29
*A. apicoargenteus** ...	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	26
*A. natronius**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	21
A. funestus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20
T. fuscopennatus ...	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
*A. cumminsi**	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18
A. longipalpis	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
A. grahami	+	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13
E. chrysogaster	+	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9
A. implexus	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
T. uniformis	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
A. ingrami	+	+	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
A. pharoensis	+	+	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
T. maculipennis	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
A. de-boeri subsp. *de-meilloni**	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
*A. lamborni**	+	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
U. ornata subsp. *mus-arum*	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
E. ferox	+	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
A. paludis	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
A. keniensis	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
F. mediolineata group ...	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
T. aurites	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
T. aureus	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
T. microannulatus ...	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
*A. haworthi**	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
*A. mutilus**	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
E. inornatus group ...	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
C. tigripes	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
A. obscurus	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
U. annulata group ...	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
U. fusca	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
F. plumosa	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
A. fraseri	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
A. domesticus	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
A. abnormalis group* ...	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
*A. palpalis**	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1

Aëdes.

The members of this large genus show marked diversity of behaviour and it is convenient to consider them in two groups, *Aëdimorphus* and *Banksinella* spp., which are mainly ground-haunting mosquitoes, and *Mucidus, Finlaya* and *Stegomyia* spp., which have pronounced arboreal tendencies.

The vertical distribution of the *Aëdimorphus* and *Banksinella* spp. is shown collectively in fig. 3. It will be noted that the distribution was essentially similar

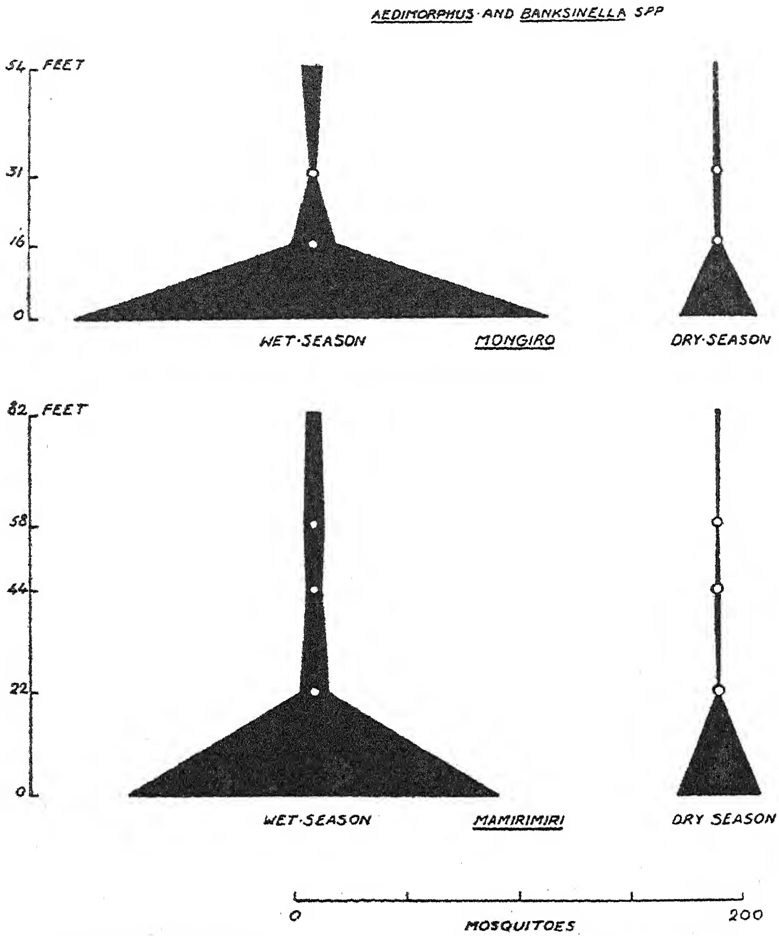


FIG. 3.—The vertical distribution of 2 subgenera of *Aëdes* (*Aëdimorphus* and *Banksinella*) shown collectively.

to that of *A. gambiae*, but an even more marked preference for the ground-level was apparent, 85 per cent. of the total catch having been taken at the ground stations in the rains and 91 per cent. in the dry season. Among the scarcer species (*A. haworthi, A. mutilus, A. domesticus*, the new species of the *A. abnormalis* group, *A. lamborni* and *A. palpalis*) only one specimen was taken above ground level. The much more abundant *A. tarsalis* group, *A. cumminsi* and *A. circumluteolus*, were also largely confined to the ground, though fair numbers were taken on the 16- and 22-foot platforms and three at heights of over 50 feet. The only species in the two subgenera which showed distinct arboreal tendencies was *A. natronius*, 57 per cent. of the total for this species having been taken at heights

of more than 50 feet. In the wet-season catches *A. natronius* was represented at every level in both areas.

Though the *Aëdimorphus* and *Banksinella* spp. showed a very marked reduction in numbers in the dry season, it will be seen that most of them were present and that some occurred in the dry-season catches only (Table II). With regard to consistency of appearance in the catches, it should be noted that the *A. tarsalis* group and *A. circumluteolus* were taken on 35 and 34 days respectively and *A. natronius* on 21 days. It is known from the evidence of large routine ground-level catches that the *A. tarsalis* group are by far the most abundant Culicines at Mongiro throughout the year (though this predominance only becomes fully apparent when moving baits are employed), but their preference for biting at ground-level renders it unlikely that they play any important part in the local epidemiology of yellow fever among monkeys.

The biting-cycle of the *A. tarsalis* group (Table III and fig. 8) showed a pronounced difference from results previously obtained, for, while earlier observations indicated a marked peak of activity after sunset and fair numbers biting during the night, the present series showed a very marked peak in the morning (06-10 hours), no peak after sunset and only small numbers biting by night. The reasons for this difference are not understood, but it seems likely that the biting-cycle of this group (and indeed of several *Aëdimorphus* spp.) lacks the clear-cut character shown by the cycles of certain other mosquitoes. As in previous catches, *A. cumminsi* was taken biting throughout the 24 hours, with its highest peak of activity after sunset in the 18-22 hours period (fig. 8). *A. natronius* showed a very pronounced peak in the post-sunset period, mainly between 18 and 20 hours, when 23 (55 per cent. of the total for this species) were taken. In its preference for this time, combined with its prevalence in the main forest canopy, it shows great similarity in behaviour to *A. africanus*. In the previous Bwamba catches an unsatisfactory sample of *A. circumluteolus* was obtained, showing almost equal numbers biting by day and by night. It was noted at the time that the evidence of routine catches suggested that this species is mainly diurnal, its preferred biting-periods being the morning and late afternoon. Present findings largely confirm this, by far the most important period being the afternoon between 14 and 18 hours, when 38 per cent. of the total for this species was obtained. Though large numbers were also taken during the night, 34 per cent. of these were captured between 18 and 19 hours—*i.e.*, just after sunset and before the light had faded completely.

An entirely different picture is presented by *Mucidus*, *Finlaya* and *Stegomyia*, all the Bwamba species belonging to these subgenera being arboreal to a greater or lesser degree. Their vertical distribution is shown collectively in fig. 4.

The only species of *Mucidus* represented in the catches was *A. grahami*. This mosquito had previously been regarded as very scarce in Bwamba, but it was taken in catches in both areas, during both seasons, 44 per cent. of the total being obtained at heights of over 50 feet. It is obviously a nocturnal species (Table III and fig. 8), though in routine ground-level catches specimens have occasionally been taken by day. It is clear that previous ideas as to its scarcity in Bwamba have been considerably influenced by the fact that most of the work consisted of ground-level catches made during the morning hours. Its prevalence in the forest canopy has been amply confirmed by the results of subsequent routine catches on high tree-platforms.

In the case of the subgenus *Finlaya* one species (*A. longipalpis*) is very definitely arboreal, while the other (*A. ingrami*) though taken several times on high platforms, is less markedly so. Of a total of 40 *A. longipalpis* 28 (70 per cent.) were taken at heights of over 50 feet. This finding is in agreement with the observations of Garnham and others (1946) who obtained 82 per cent. of their adult specimens on a platform 55 feet high in the Kaimosi Forest, Kenya. These workers also noted that *A. longipalpis* prefers high tree-holes for breeding. The dry-season catch of this species was small, but six were taken at Mamirimiri, all on the 58-foot platform,

which is in a dense part of the main forest canopy. It seems clear that the canopy is the preferred habitat of this species and that it may be very largely confined to this environment during dry weather. The biting-cycle of *A. longipalpis* (fig. 8) shows that it is a diurnal mosquito, reaching its peak activity in the 10-14 hours period—a finding in agreement with the results of previous 24-hour catches in Bwamba. *A. ingrami* was rather poorly represented in the catches. It appears to be mainly diurnal and only moderately addicted to biting at the higher levels. It is fairly common in ground-level catches in Bwamba. Garnham and his co-workers obtained adults in the Kaimosi Forest at ground-level only.

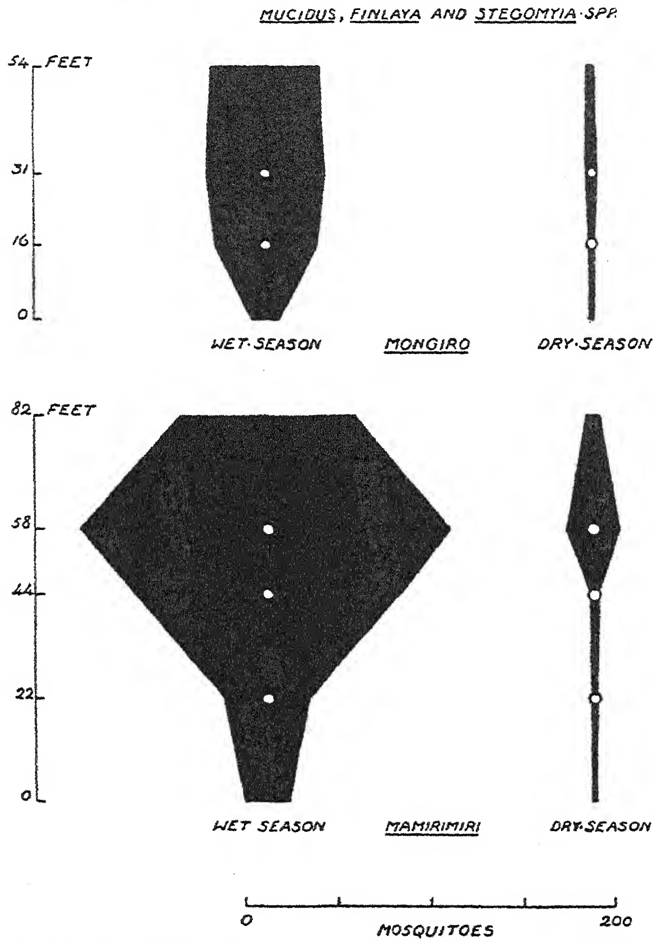


FIG. 4.—The vertical distribution of 3 subgenera of *Aëdes* (*Mucidus*, *Finlaya* and *Stegomyia*) shown collectively.

The important subgenus *Stegomyia* includes the classical vector of human yellow fever (*A. aegypti*), another proved vector of the human disease in Uganda (*A. simpsoni*) and four species known to be capable of transmitting the virus under laboratory conditions (*A. metallicus*, *A. africanus*, *A. luteocephalus* and *A. vittatus*). It is felt, therefore, that particular interest attaches to the observation that some of the most markedly arboreal mosquitoes so far found in Bwamba belong to this subgenus. The wet-season catches having demonstrated the prevalence of *Stegomyia* spp. at high levels, the question arose as to whether these mosquitoes could survive a long period of dry weather in the adult state (and could thus maintain yellow fever virus in a forest area between successive wet seasons) or

whether they relied entirely on their drought-resistant eggs at such times. The dry-season catches were made principally in order to gain information on this point.

A. fraseri is scarce in Bwamba and only one specimen was obtained during the present catches (at Mongiro, on the 31-foot platform). Garnham and others found this species prevalent at 55 feet in the Kaimosi Forest. *A. de-boeri* subsp. *de-meilloni* is quite a common mosquito in the Bwamba forests, and it is sometimes taken in fairly large numbers in ground-level catches made during the day. The sample obtained during the present investigation is inadequate for discussion. As has been mentioned in a previous communication (Haddow, 1945a), *A. aegypti* occupies a peculiar position in Bwamba, being present in some uninhabited areas of the Semliki Forest. Garnham and his co-workers have also found it " scattered rather profusely " through the Kaimosi Forest, where one adult has been taken biting on a platform 43 feet high. Though not represented in the 40 catches under discussion, it is interesting to note that in subsequent routine work 13 specimens have been taken biting in the sunset period at heights of over 50 feet.

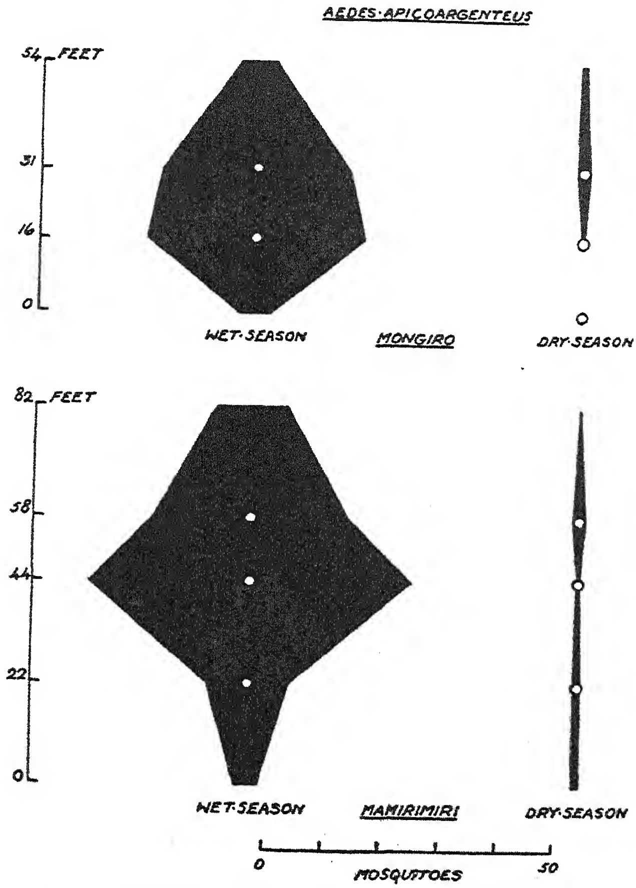


FIG. 5.—The vertical distribution of *Aëdes apicoargenteus*.

A. apicoargenteus was very well represented in the wet-season catches in both areas (Table I). At Mongiro 86 per cent. of the wet-season catch of this species was taken at the 16- and 31-foot levels, *i.e.*, mainly in the understorey foliage below the main forest canopy but above the undergrowth and small stunted trees (fig. 5). At Mamirimiri considerable numbers were taken in the main canopy at 58 feet, but by far the highest concentration was found in the understorey at 44 feet, where 47 per cent. of the total wet-season catch for this area was obtained. Garnham and

others, who obtained specimens on tree-platforms in the Kaimosi Forest, state that there it is most prevalent in second-growth with open canopy, but in Bwamba it is present in all types of forest and is common in primary lowland rain-forest with dense closed canopy as at Mongiro and Mamirimiri. The dry-season catches of *A. apicoargenteus* were very small, representing less than 4 per cent. of the wet-season yield, and it seems likely that under such unfavourable weather conditions it depends to a large extent on its drought-resistant eggs. In spite of this scarcity in the dry season, it must be regarded as one of the commonest arboreal Culicines in Bwamba, and it was taken on 26 of the 40 days of the investigation (Table V). *A. apicoargenteus* is obviously a diurnal mosquito, reaching its highest biting-activity in the afternoon between 14 and 18 hours (Table III and fig. 8). Though all the specimens obtained in the present series of catches were taken by day, previous 24-hour catches and routine catches in Bwamba have shown that small numbers may sometimes be taken during the night. In spite of its prevalence, wide distribution and arboreal habits, the relationship of *A. apicoargenteus* to yellow fever must be regarded as doubtful, in view of Bauer's negative results in transmission experiments with this species (1928).

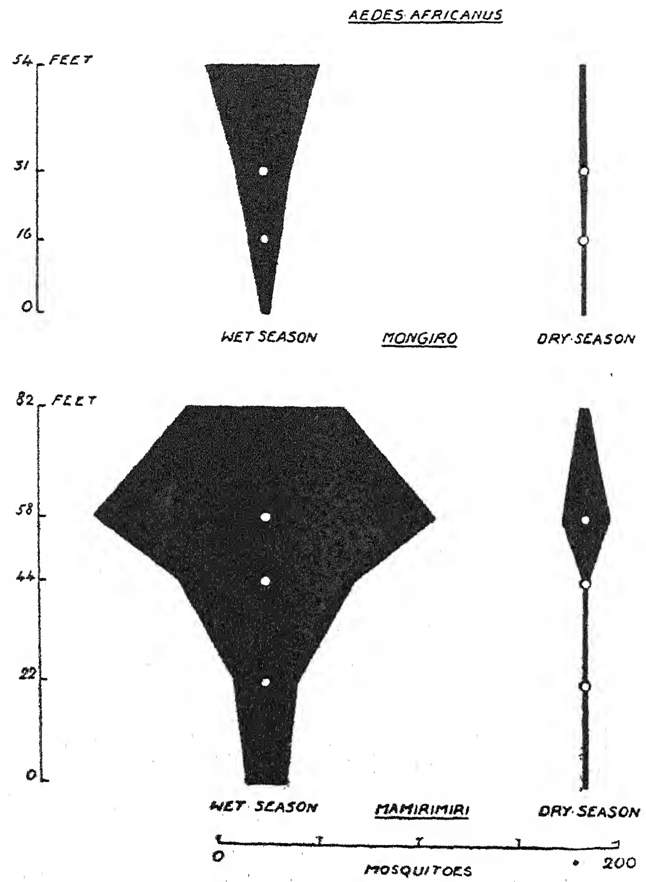


FIG. 6.—The vertical distribution of *Aëdes africanus*.

The catches at Mongiro and Mamirimiri showed clearly that *A. africanus* is the dominant arboreal Culicine of the lowland forest. Its preference for high levels was very marked, and the results from both areas showed that its prevalence increased with increasing height till a maximum is reached in the main forest canopy at a height of 50-60 feet above ground (fig. 6). Not only did *A. africanus* bite in

large numbers, it was also consistently present, being taken in 32 of the 40 catches (Table V). In the dry season, though the catch was much reduced, adults were taken in numbers large enough to be interesting, 27 having been obtained at Mamirimiri and seven at Mongiro. All these dry-season adults were old mosquitoes with worn thoracic pattern and often with threadbare wings. During the wet season catches, 46 per cent. of the total were taken in the forest canopy on the 54- and 58-foot platforms, but this high figure was surpassed in the dry season, when 65 per cent. were taken at these levels. This is thought to be an example of the retreat of a specialised species to its optimum habitat in unfavourable weather. The biting-cycle of *A. africanus* is particularly well defined, with a single sharp peak of activity in the 18-22 hours period (fig. 8). In view of the probable importance of this species, the detailed hour-to-hour catch records have been given (Table IV and fig. 7) and these show that 42 per cent. of the total were taken

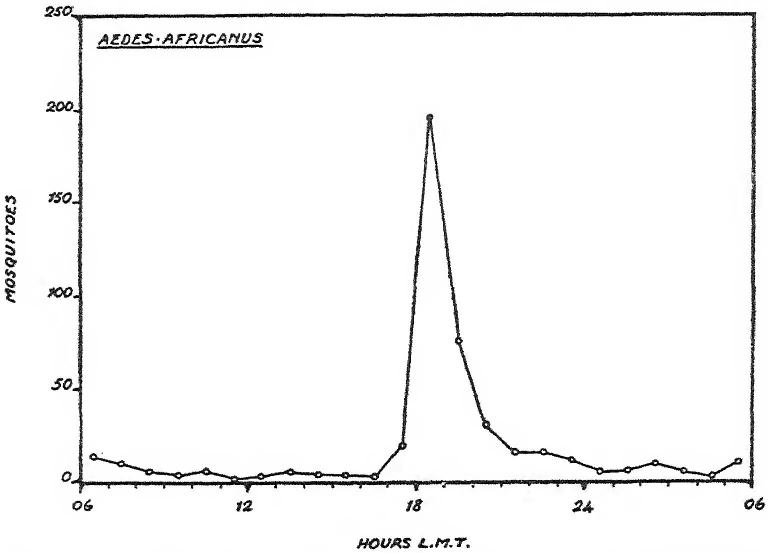


FIG. 7.—The biting-cycle of *Aëdes africanus*—hourly totals for the entire series of 40 catches.

between 18 and 19 hours, *i.e.*, in the hour following sunset, before the last light had gone. This result confirms previous work in Bwamba and is in agreement with Kerr's (1933) observations in West Africa. The main climatic features of the period after sunset are, as mentioned above, fairly high temperature combined with high atmospheric humidity and fading light. It is the only period during which high humidity and fairly high temperature occur together. This crepuscular activity of *A. africanus* is very markedly influenced by local weather. Ideal conditions are found on a still, warm evening after a sunny afternoon, and cold, rain or a slight breeze greatly reduce biting-activity at dusk. On unfavourable nights when the sunset peak has not been well-marked, a larger catch than usual may often be made during the later hours of the night, but the total never approaches that which may be expected when the weather is fine.

The writers believe that *A. africanus* is probably of major importance in the transmission of animal yellow fever in the Bwamba forests, and it may be well to summarise the evidence in favour of this view: Protection tests have shown a very high incidence of immunity to yellow fever among the monkeys of the Bwamba lowlands. Certain of these monkeys live almost entirely in the canopy

of the rain-forest, rarely descending to the ground, and it follows that they must almost certainly become infected in the canopy itself. The dominant mosquito of the forest canopy is *A. africanus*, a species with a wide distribution, known to be capable of transmitting yellow fever virus in the laboratory. It was included in the mixed lot of *Aëdes* spp. taken in uninhabited rain-forest, from which yellow fever virus was isolated in 1944. Further, it has been found that in Bwamba this species can survive periods of marked drought and that old females can be taken biting in the forest canopy at such times. Among the Bwamba monkeys some species (such as *Papio doguera tesselatus*, Elliot) spend much of their time by day on the ground, yet these show as high an incidence of immunity to yellow fever as do the more arboreal species. From this it is deduced that transmission probably takes place at a time when all species of monkeys are in the trees, *i.e.*, at night. *A. africanus* reaches its peak activity after sunset, at a time when the monkeys have completed their evening meal and have gone to sleep in their usual sleeping-trees (most monkeys take up their positions for the night about 20 minutes before dusk). It may be mentioned that, as a result of these observations, present routine mosquito work in Bwamba is almost entirely confined to evening catches on high tree-platforms, in order to obtain the maximum yield of this species for the inoculation of rhesus monkeys.

Eretmapodites.

This small genus of diurnal mosquitoes is particularly well represented in Bwamba. Several species are quite common in ground-level catches made during the day in forest, but only the *E. chrysogaster* group are sufficiently abundant to be of any potential importance. *Eretmapodites* spp. are best captured by moving from point to point, with brief halts in favourable spots, and in the present series the stationary baits attracted small numbers only. Bauer's experiments (1928) have shown that *E. chrysogaster* can transmit yellow fever virus in the laboratory, but as this species seems to be mainly confined to ground-level (Table I) it is unlikely that it can be of major importance in the local epidemiology of animal yellow fever. The *E. inornatus* group and *E. ferox* were both taken on tree-platforms, but it is doubtful whether these scarce mosquitoes can be of any practical interest. It should be noted that in the Kaimosi Forest Garnham and others took adult *Eretmapodites* spp. biting at ground-level only.

Culex.

As no attempt was made to distinguish the numerous small *Culex* (representing many species) little can be said about this genus. *Culex* spp. were abundant at all levels, as is shown in Table I. Their vertical distribution was apparently irregular, but this is doubtless due to the heterogeneous nature of the sample. It has been suggested (Edwards, 1941) that the majority prefer avian, reptilian or amphibian blood, and this may explain their abundance in the higher levels of the forest, as at Mongiro there is a large and varied fauna of birds and tree-frogs, while arboreal lizards (Geckonidae, etc.) and tree-snakes (notably *Rhamnophis ituriensis*, Schmidt) are also present. The biting-cycle of the small *Culex* spp. showed a distinct peak of activity in the 18-22 hours period (Table III and fig. 8), an observation in agreement with the results of previous 24-hour catches in Bwamba. It seems that, whatever their individual preferences for level may be, the local species are definitely crepuscular. Routine catches support this belief, as *Culex* spp. are rarely abundant in day-catches of mosquitoes biting at ground-level, while they almost always predominate in day-catches of mosquitoes resting in the forest undergrowth. It is interesting to note that they were much more abundant in the dry season than in the rains, particularly at Mongiro.

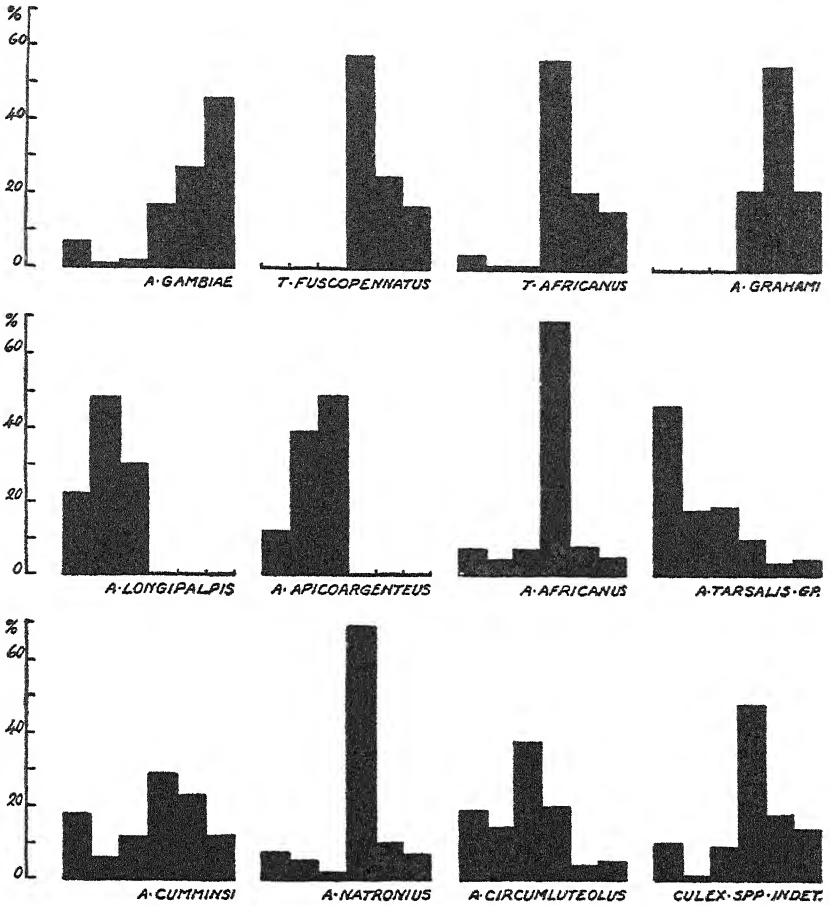


FIG. 8.—The biting-cycles of the more important species by 4-hour periods. The columns of the histograms represent the 6 4-hour periods, namely :—06–10, 10–14, 14–18, 18–22, 22–02 and 02–06 hours. Thus the first 3 columns show day catches and the second 3, night catches.

The Forest Microclimate.

As in previous work in Bwamba, the study of the microclimate consisted in the simultaneous comparison of stations. Two thermographs, two hygrographs and two identical Stevenson screens were used, the instruments having been compared and calibrated before the work was begun. Mongiro was chosen for the climate comparisons, the ground-level station being taken as the standard. The climate at this station was compared with that at each of the three tree stations in turn, the instruments being exposed for 5-7 days in each series. It would, of course, have been preferable to compare all four stations simultaneously, but sufficient instruments and screens were not available. The Mongiro readings were begun shortly after the end of the wet-season catches of 1944, in rather warm dry weather. Subsequently, similar series of observations were made at Mamirimiri, during a spell of extremely wet weather in October, 1944, but the Mamirimiri results will be discussed only briefly. Light readings were taken on a single clear sunny day at Mongiro. A small photoelectric cell with a scale graduated in arbitrary units

was employed and the figures are, therefore, of comparative value only. The light readings were taken in rapid succession at each station at each clock-hour from before sunrise till after sunset. A white cloth draped over an inverted bowl was used as a standard reflecting surface, the reading being made at a distance of 6 inches. During the observation the photometer was moved through an arc of 90° round the most brightly illuminated side of the bowl and the mean reading was recorded. This was necessary as the illumination was by no means regular, usually consisting of moving leaf-shadows with spots of bright sunlight between. As 4-hour periods have been used in the discussion of the mosquito figures, it has seemed best to use similar periods for the consideration of light readings and other climate records.

In the case of the light readings (Table VI and fig. 9) a fairly even gradient

TABLE VI.

Light-intensity comparisons at Mongiro, arbitrary units, by 4-hour periods.

Period (hours L.M.T.)	*0′*	*16′*	*31′*	*54′*
06–10	26	40	89	168
10–14	36	70	111	178
14–18	13	20	47	105
18–22	0	0	0	0
22–02	0	0	0	0
02–06	3	4	5	8

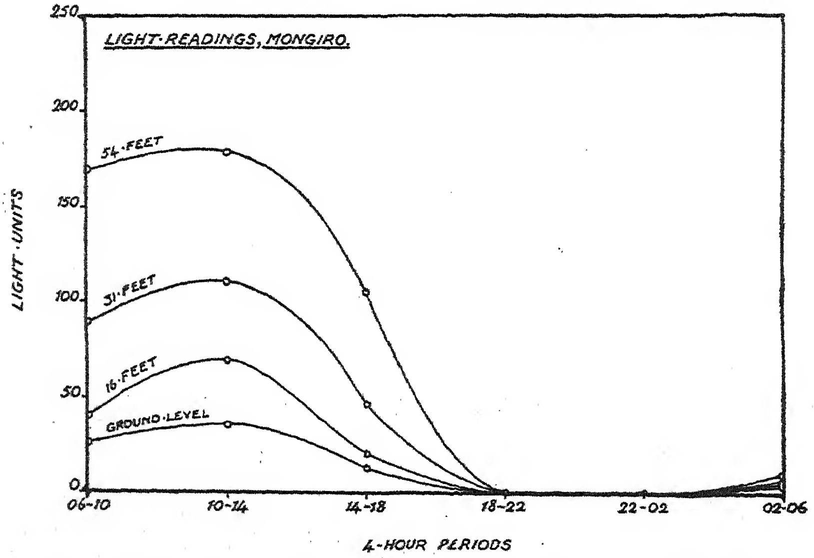


FIG. 9.—Light-intensity readings (arbitrary units) taken on a single day at Mongiro, all stations (4-hour means of hourly readings).

was obtained, the light increasing regularly with increasing altitude, but it must be emphasized that the present observations should be considered as applying to a particular set of stations only, as Bates (1944) has pointed out that it is easy to find types of forest where the light may be greater at ground-level than in corresponding parts of the canopy. At Mongiro the maximum light intensity was

recorded at all stations in the midday period, but again this must be regarded as a particular case. For example, a station in the lower part of the crown of a giant tree above the main forest canopy would almost certainly show the highest readings in the early morning and late afternoon, when the slanting sunlight would not be occluded by the foliage.

Turning to the other main factors which make up the microclimate—temperature, relative humidity and saturation deficiency—it is first necessary to emphasize the marked equability and constant high humidity of the air just above the forest floor, a subject which has previously been discussed in some detail (Haddow, 1945b). A trace taken at the ground-level station at Mamirimiri during October, 1944, demonstrates this stability of the ground-level microclimate particularly well (fig. 10). In this case it will be noted that during a period of four days the

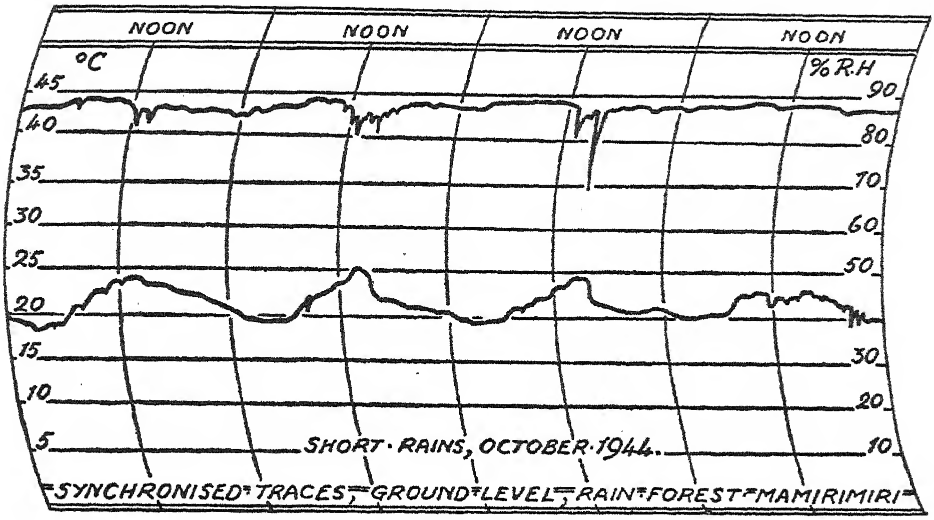


FIG. 10.—Thermograph and hygrograph traces taken simultaneously at ground-level in the forest at Mamirimiri, to show the marked equability, coolness and high humidity of the atmosphere just above the forest floor.

temperature only once rose above 25°C. and never fell below 18°C. The relative humidity trace shows even greater stability, never rising above 90 per cent. and only once, for a very brief period, falling below 80 per cent.

In the case of the Mongiro climate comparisons (Table VII and fig. 11) it will at once be seen that the differences between the ground-level station and that at 16 feet are small and insignificant, both by day and by night. On the other hand, marked differences may be noted between the ground-level results and those obtained at 31 and 54 feet. Further, it will be seen that the differences between the ground and the 54-foot level are not much greater than those between the ground and 31 feet. In other words, there are two main microclimatic strata in the Mongiro forest. The lower, characterised by extreme equability, marked coolness and high atmospheric humidity, extends from the ground upward to at least 16 feet, *i.e.*, through the undergrowth to the discontinuous zone of small trees mentioned above. The upper stratum extends from the lower limit of the understorey upward to the main canopy, and possesses a microclimate markedly different from that of the lower stratum. The traces from the 31- and 54-foot stations show many of the characteristics of records made in the open air—a marked diurnal rise in temperature and saturation deficiency, with a correspondingly pronounced fall in

relative humidity. More particularly, these traces show numerous sudden short-duration fluctuations (caused by puffs of wind, passing clouds, etc.) which are conspicuously absent from traces made in the lower stratum. During the night, and particularly in the period before dawn, the differences between the two strata are much reduced and are almost certainly not significant, but they reappear soon after sunrise and persist until long after sunset. Once again it is clear that these findings apply to a particular type of forest—though it is a type which predominates in much of the Bwamba area. It is known, for example, that in certain South American forests the various climatic factors present definite vertical gradients, temperature and light increasing fairly regularly with increasing height, while relative humidity decreases (Bates, 1944) and it seems likely that in much of the main Ituri Forest of the Congo, where an extremely heavy closed canopy prevents the development of dense undergrowth, climatic gradients rather than successive strata are to be expected. On the other hand, some parts of the Semliki Forest are likely to show even more sharply-delimited strata than does Mongiro. In some rather dry areas, for example, the ironwood (*C. alexandri*) occurs in almost pure stand, forming an extremely light (though closed) canopy. The result is that the zone of small stunted trees—discontinuous at Mongiro and Mamirimiri—forms a dense belt of foliage at 12-20 feet, below which the air is cool and very humid and light intensity is low, while above the conditions approximate to those of the open air.

TABLE VII.

Climate comparisons at Mongiro, by 4-hour periods.

Period (Hours L.M.T.)	06–10	10–14	14–18	18–22	22–02	02–06
Temperature, °C.						
Ground level	21	25	24	22	21	20
16 feet	22	25	24	22	21	20
Ground level	23	25	24	22	20	20
31 feet	23	27	26	23	21	20
Ground level	21	24	23	21	20	19
54 feet	23	27	27	24	22	20
Relative humidity, per cent.						
Ground level	87	81	87	87	88	89
16 feet	87	78	86	89	89	90
Ground level	90	85	87	88	91	92
31 feet	81	67	73	80	88	88
Ground level	90	85	85	88	90	90
54 feet	82	66	71	80	88	90
Saturation deficiency, mm.						
Ground level	2·5	4·5	3·0	2·5	2·5	2·0
16 feet	2·5	5·5	3·0	2·0	2·0	1·5
Ground level	2·0	3·5	3·0	2·5	1·5	1·5
31 feet	4·0	9·0	7·0	4·5	2·5	2·0
Ground level	2·0	3·5	3·5	2·0	1·5	1·5
54 feet	4·0	9·0	8·0	4·5	2·5	1·5

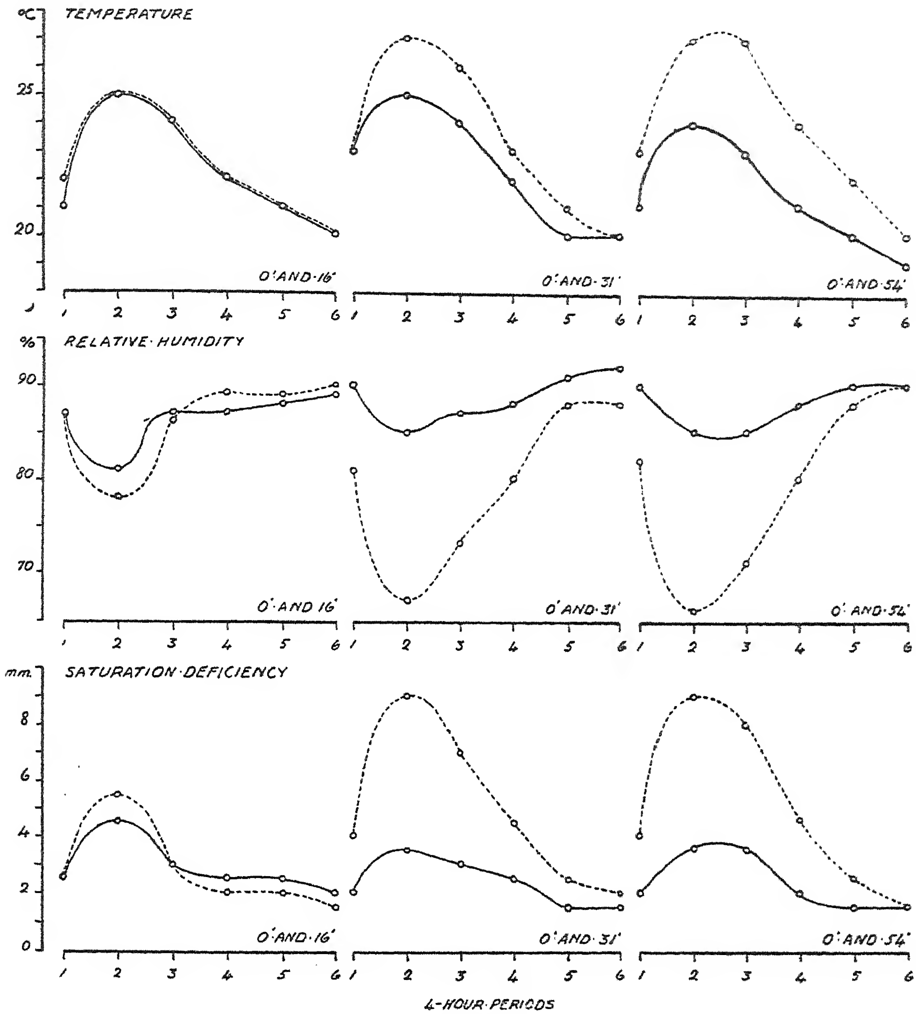


FIG. 11.—The microclimate in forest at Mongiro. Successive comparisons between the ground-level station (0′) and the 3 tree-platforms (16′, 31′ and 54′). The plotted points are 4-hour means calculated from hourly readings of thermograph and hygrograph traces (saturation deficiency also calculated from these traces). The numbers 1–6 represent the 6 4-hour periods, namely:—06–10, 10–14, 14–18, 18–22, 22–02 and 02–06 hours. Continuous line—ground-level station; broken line—tree-stations.

The above discussion applies to warm dry weather such as that immediately following the wet-season catches of 1944. This period was followed by an exceptionally rainy spell in October and November, and at this time series of readings were made at Mamirimiri. It was believed that the wet weather would do much to reduce the differences between the upper and lower forest levels, and Mamirimiri was chosen mainly on account of the 82-foot platform—the highest station available for study. In the first week of this second set of readings, a comparison between the ground-level station and the 22-foot platform showed that the differences between these levels were insignificant. This was followed by a comparison between the ground-level station and the 44-foot platform, and once again the differences were found to be very slight, in the case of both temperature and relative humidity.

As it was feared that the heavy rain might end before the investigation could be completed, the 58-foot level was omitted and the third week was devoted to a comparison between the ground-level station and the 82-foot platform. In this instance quite definite differences were noted, but the records showed that there was less divergence between the ground and the 82-foot level at Mamirimiri in wet weather than between the ground and the 31-foot level at Mongiro in warm dry weather—this in spite of the fact that the 82-foot platform was slightly above the main forest canopy, while the 31-foot platform was in the lower level of the understorey foliage.

Thus in dry weather there are two climatic strata in the Bwamba forest, the lower very equable, cool and humid, the upper warmer, drier and with quite a pronounced daily range. This upper level is subject to the influence of slight climatic incidents outside the forest. During the later hours of the night and in wet weather the differences between the upper and lower forest levels are markedly reduced, and the stable and humid microclimate of the forest floor extends upward for a considerable distance—at least as far as the main foliage of the understorey.

The mosquito fauna of the upper microclimatic stratum differs markedly from that of the lower. A good example is shown by the genus *Aëdes*, in which two subgenera (*Aëdimorphus* and *Banksinella*) are largely confined to the lower stratum, while three others (*Mucidus*, *Finlaya* and *Stegomyia*) find their optimum habitat in the upper. As has been pointed out above, some of the species (such as *A. longipalpis* and *A. africanus*) show a tendency to confine their activity to a particular level during dry weather, while in the rains, when the climatic differences between the upper and lower levels of the forest are slight, they may be taken at all heights, though still occurring in maximum concentration at the same altitude as in the dry season.

While the climatic picture is in many ways instructive, it is felt that an enormous amount of work must be done before general conclusions can be drawn. The large number of different types of forest, coupled with the extreme variability in the height and foliage of individual trees and of individual species of trees, indicates that the subject must be approached with care. For example, in the case of a mosquito which exhibits a well-marked vertical distribution, it is not yet possible to say whether this behaviour depends on general microclimatic factors or upon such other features of the environment as density and type of foliage, vertical distribution of the preferred food animal, etc. While the present investigation has shown that at Mongiro and Mamirimiri *A. africanus* reaches its optimum at a height of 50-60 feet above ground, there is at the moment no information to indicate whether it prefers to bite at this height or whether—as seems much more likely—its preferred zone bears a relationship to the local structure of the forest. Even if it were found that this species prefers the main canopy in forest of all types, much work would still remain to be done on the microclimate of the canopy, not merely in different kinds of forest but also in different individual trees within the same small area, in relation to their population of this species.

Summary.

1. During the past eight years field investigations on the epidemiology of yellow fever have been carried out in Bwamba County, a small heavily-forested area in the extreme west of Uganda.

During the course of this work yellow fever virus has been isolated from a human case, from *Aëdes* (*Stegomyia*) *simpsoni*, Theo., and from a mixed lot of *Aëdes* spp. taken in uninhabited rain-forest.

As it is known that yellow fever is endemic among the monkeys of the Bwamba forests and that a high rate of immunity is shown by certain species that rarely descend to the ground, it was concluded that an arboreal mosquito was the most

likely transmitter of yellow fever among monkeys, and an investigation of the arboreal mosquito fauna was begun.

2. A description is given of the forest areas chosen for the work.

3. The investigation consisted of series of continuous 24-hour catches, carried out simultaneously at ground-level and on tree-platforms of various heights up to 82 feet. Twenty such catches were made during the rains and 20 in the dry season.

4. *Anopheles gambiae* was found to be by far the commonest mosquito at all levels, and over 30,000 (representing 93 per cent. of the total for all species) were taken. The occurrence of this usually endophilic mosquito in uninhabited rain-forest has been discussed in a previous communication and receives further comment in the present paper. Maximum biting-activity occurs between midnight and dawn.

5. Several species of *Taeniorhynchus* were taken above ground-level. *T. africanus* occurred in fair numbers at heights of over 50 feet.

6. Within the genus *Aëdes*, two subgenera (*Aëdimorphus* and *Banksinella*) bite mainly at ground-level, while *Mucidus, Finlaya* and *Stegomyia* spp. show distinct arboreal tendencies, particularly well-marked in the cases of *A. grahami, A. longipalpis, A. apicoargenteus* and *A. africanus*.

A. africanus was found to be by far the most abundant aboreal Culicine, attaining its highest concentration in the forest canopy, where it was taken biting even in very dry weather. This species is definitely crepuscular, as is shown by the fact that 42 per cent. of the total catch was taken in the hour following sunset.

It is believed that *A. africanus* may play a large part in the transmission of yellow fever among monkeys. Evidence in support of this view is discussed.

7. In the case of the genus *Eretmapodites* the only really abundant Bwamba species (*E. chrysogaster*) was taken at ground-level only.

8. No attempt was made to distinguish the numerous small species of *Culex*. It was noted, however, that members of this genus were common at all levels and that their biting-activity showed a marked peak in the hour after sunset.

9. Observations on the microclimate at various levels indicate that in the forest area concerned there are two main microclimatic strata. The lower stratum is very equable, cool and humid. The upper, which includes most of the understorey and canopy foliage, shows a much greater daily range and has many points in common with the climate in the open. During wet weather and by night the differences between these strata are much reduced. The relationship of the microclimate to mosquito behaviour is discussed briefly.

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THE HABITS AND CONTROL OF THE RED LOCUST IN OUTBREAK AREAS AND ELSEWHERE.

By A. P. G. Michelmore, B.A., F.R.E.S.

Introduction.

The principles of locust control were revolutionised by Uvarov's phase theory (Uvarov, 1921), which was definitely proved to apply to the Red Locust, *Nomadacris septemfasciata*, Serv., only some 13 years ago (Uvarov, 1924; Faure, 1932, 1935; Mossop, 1933, 1933a; Michelmore & Allan, 1934). This theory led to the discovery that outbreaks of locusts, even on a continental scale, usually started in a few small places, with the change of the solitary or grasshopper phase of the insect into the gregarious or locust phase. A few small swarms then left these areas and bred up in following seasons giving rise to a major outbreak. This made it clear that the more logical way to attack an outbreak was at its source, rather than to wait until waves of huge swarms descended on the crops of thickly inhabited areas.

Researches by Allan, Harris and the writer (Allan, 1931; Harris, 1933; Michelmore, 1934, Dep. Agric., S. Afr., Inter-State Locust Conf., 1935), supported by the work done by the entomologists of the invaded countries in collecting records of swarm movements (summarised by Uvarov, 1933, 1933a), proved that the last great outbreak of the Red Locust started almost certainly from two restricted areas

only. These were the neighbourhood of Mweru wa Ntipa (Mweru Marsh), in the extreme north of Northern Rhodesia, and Lake Rukwa, in the south-west of Tanganyika Territory. Another separate outbreak took place round Lake Chad in northern Africa (Lean, 1931; Golding, 1934) but was only small.

As long ago as 1936 a scheme for the permanent international control of these and other areas suspected as being dangerous was put forward by the United Kingdom delegation to the Fourth International Locust Conference, which adopted it in its recommendations (International Locust Conference, Cairo, 1937, pp. 82-86; Faure, 1937; Michelmore, 1937). An enlarged version of the scheme was agreed to by the British and Belgian Governments in 1938 (Internat. Locust Conf., Brussels, 1938, pp. 77-81, 307-310). The war delayed the realisation of this scheme, and it was only in 1941 that the writer was sent out single-handed to Northern Rhodesia to found the Central African Red Locust Control Organisation, and by April, 1942, field work was started.

The outbreak centres were patrolled constantly by native scouts under European supervision. Incipient outbreaks of Red Locust hoppers were found and destroyed in the Rukwa area in the rainy seasons of 1942-43 and 1943-44. For the 1944-45 season a more intensive campaign had been planned but the outbreak proved to be so much more serious than was anticipated, that the preparations were inadequate and a considerable number of swarms reached the flying stage and left the outbreak area. The chief difficulty was shortage of European supervision. An increase of staff had been asked for and approved, but men could not be found on account of the war. In order to crush this new outbreak before it gets quite out of hand a very extensive campaign has been planned for the 1945-46 season.

The object of this paper is to describe the control methods used in these three past campaigns, and to discuss the whole question of control methods in the light of the experience gained. While much has been written about locust destruction in general, little has been published on the special problems due to the habits of the Red Locust, and still less of those caused by the nature of the country favoured by this species. These problems are by no means all the same as for other species of locusts, and this paper is an attempt to show how methods used against the latter must be modified for the Red Locust.

Habits and Vulnerability of the Red Locust.

This section is devoted to a description of such habits of the Red Locust as have a bearing on control work with a discussion of the effects of these on possible methods of control.

A. Phase *solitaria.*

1. *General habits.*

The solitary phase of the Red Locust, in all stages, lives scattered thinly in the grasslands of the flood plains. The hoppers are sometimes slightly gregarious but are inactive and inconspicuous. When the adults are numerous, they tend to form concentrations in tall grass areas in the latter part of the dry season, which makes them easier to attack, although a proportion of the locusts in an area always remain scattered. With the beginning of the rains they scatter all over the plains, and even enter the edges of the bush bordering on the grasslands. Occasionally a group of locusts that has concentrated in the dry season behaves as a true swarm for a few days during the early rains and migrates for a few miles in a body before scattering again. There is no concentration for egg laying.

2. *Necessity of treating the entire surface of outbreak centres for complete control.*

Most or all of the population of a permanent breeding place are scattered and this makes control difficult. Control would theoretically be possible by some method of destruction that could be used wholesale over the entire outbreak centre. This would involve treating many hundred square miles and is not at present practicable, although it is possible that some insecticide may later be found which could be applied by aircraft over such large areas. It is probable that the cost of such a method would be prohibitive, and that it might have serious effects on the other denizens of the area.

3. *Possibility of altering conditions in outbreak centres.*

Another possible way of control would be to change the habitat of the locusts so as to make it unsuitable for them, or at least for their transformation from the solitary to the swarming phase. Our knowledge of the Red Locust is not yet sufficiently complete to enable us to indicate ways of doing this in all outbreak areas. Further research may well reveal other methods, but so far only three ways have appeared to be theoretically possible. The first is to drain the grasslands so that they become suitable for trees (Michelmore, 1939), and therefore unsuitable for solitary locusts (Michelmore, 1934, 1937). The second is to flood them out (Michelmore, 1934). The third is to prevent the grass from being burnt, the writer's observations (unpublished) at Rukwa having shown that the solitary Red Locust will not lay eggs in ground covered with a mat of unburnt grass.

(*a*) *Draining.*—This is out of the question at Lake Rukwa, as the lake lies in a dischargeless basin. It is theoretically possible for the plains in the north end of the Rukwa basin, which drain into the lake, and for Mweru wa Ntipa and its tributary marshes, which connect with the River Kalungwishi, but in both areas the flat plains are so large that it is doubtful if drainage would be practicable. In an outbreak area where this method was feasible draining would usually be followed by natural invasion by trees. This could be hastened by planting, a method already proposed by Saraiva (1938) as a control method in outbreak areas, but this would, however, be impracticable in those at present known.

(*b*) *Flooding.*—In this case the flat plains would have to be permanently submerged up to definite sloping banks, where there would be no wide belt subject to periodic flooding and, therefore, devoid of trees. In Rukwa this method also is not possible. Firstly, there is no large river which could be diverted into the Rukwa trough to raise the lake level, and secondly, even a vertical rise of several metres would only push back the present belts of swamp grassland into the great flat areas at present covered with bush and woodland. A very large increase of water would be needed to flood completely the whole valley floor to the feet of the escarpments. In the Mweru wa Ntipa area, on the other hand, Mr. H. J. Brédo, the Belgian entomologist attached to the organisation, has learnt from the natives that the River Kalungwishi in times of flood discharges back into Mweru wa Ntipa, while its main flow continues west into Lake Mweru. The seasonal grasslands of this area lie at nearly one level and are fringed with small escarpments and bush slopes. It would, therefore, be well worth while to make a hydrographic survey, to see whether it would be possible to divert more water from the Kalungwishi, and whether by this means the shore lines could be brought up to the feet of the steeper slopes. Apart from altering fishing conditions, and destroying the Kaputa salt pans, this flooding should not interfere much with the small native population.

(c) *Preventing grass fires.*—This is the only method of the three applicable to both the known outbreak areas. It would be easier in Rukwa than round Mweru wa Ntipa, where the grasslands are less compact, but it would be unpopular with the natives, as it would make much of the plains difficult to walk through and so would interfere with their hunting and fishing. Plenty of scouts would be needed to patrol the grasslands in the dry season to prevent fires from being lit and to put them out if started. One difficulty in complete protection from fire is that each year adds to the mat of combustible material, so that an accidental fire after several years is much fiercer than an annual burning. One hundred and fifty to two hundred miles of fireguard would have to be cleared annually to protect the two most important areas in Rukwa, the great main flood plains of Rukwa North and Rukwa West. In Rukwa South the grasslands are smaller and more scattered, and there are a few villages near the lake. In this area control of fire would, therefore, be more difficult and less useful and need not be attempted until it has been tried out in Rukwa North and West. The great Upimbwe flats to the north of Rukwa are only inhabited at the edges, so that fires or people to light them would have to come from outside. The grasslands of this area are separated by wooded country, which would make it more difficult to find fires quickly, and the length of fireguard necessary to surround the area would be about 160 miles. An alternative would be to forbid all grass burning in the whole of the Rukwa valley, which would involve some 430 miles of fireguard, if the few small grasslands on the eastern shores of the lakes are ignored. It would seem advisable first to protect the main Rukwa North and West plains for a few years as a trial; the Rukwa South and Upimbwe areas, and also the Mweru wa Ntipa outbreak area, could be brought under fire control later if experience warranted it.

B. Phases *transiens* and *gregaria*.

Since the control of the solitary phase needs more extensive work than the available staff could cope with, control work in the outbreak areas up to date has been confined to bands and swarms of phases *transiens* and *gregaria*, as it has, of course, in the invasion areas. This method can be prefectly adequate, as it is only when locusts form swarms that they become dangerous to crops. It has the advantage that treatment is confined to the actual areas occupied by individual swarms, instead of to the whole countryside.

1. *Eggs.*

With some species of locusts and grasshoppers useful work can be done by digging the egg packets out of the soil. In the case of the Red Locust the egg holes themselves are difficult to find, except where very dense layings by large swarms during a severe outbreak have occurred. The females give few clues as to where they have laid, owing to the fact that they lay by night and that the swarms break up for the purpose.

2. *Hoppers.*

(a) *Length of life.*—The hoppers of the Red Locust pass through six stages in usually about 2-2½ months. This period is rather longer than that taken by some other species of locusts, but its length is an advantage for control measures based on hopper destruction.

(*b*) *Size of bands.*—As with other locusts, the gregarious bands are small at first, often less than a metre in diameter. As the hoppers grow and move about, the original bands enlarge and amalgamate with others so that in severe outbreaks miles of country may be more or less infested by hoppers in the later stages. The largest bands yet found in incipient outbreaks in the outbreak centres have measured about 500×200 metres. In some conditions bands tend to disperse rather than amalgamate. The growth of bands even without amalgamation makes it advisable to destroy them at as early a stage as possible, as smaller areas have then to be covered, but an early start may make it necessary to go over the same ground several times in order to deal with successive hatchings.

(*c*) *Habitat preferences.*—The Red Locust is at home in wetter and more vegetated countries than most other African locusts. The hoppers of this species also differ from those of the other important African species in showing a much stronger preference for tall and dense grass. Hoppers of phases *solitaria* and *transiens* are seldom found on the ground. Even in actively marching *gregaria* bands only some of the hoppers walk or hop along the ground, others hop from leaf to leaf. Tall grass is preferred to short. Actively marching bands will cross bare spaces or areas of short grass, but the journey is done hurriedly, there seems to be hesitation in leaving the tall grass for the short, and the hoppers again congregate more densely on the tall grass on the far side. The preference for tall grass makes scouting for bands more difficult than with other species and it also impedes control operations. In Desert Locust campaigns almost all the work can be done by motor transport in some countries, but in Red Locust country, and especially in the marshy outbreak areas, nearly everything has to be done on foot. Early attempts at baiting the Red Locust had little success, until it was found that the bait had to be thrown on to the grass. Now that the technique is known, baiting can be done with success, though still not as easily as with the Desert and Brown Locusts.

(*d*) *Activity.*—The hoppers of the Red Locust differ somewhat in activity from those of the other two chief tropical African locusts, the Migratory and the Desert. The Red Locust hoppers are more agile and more wary but less active. This difference has an important bearing on control measures. The lesser activity lessens the danger of bands coming from a great distance into cultivated land, but it is likely to cause a band to stay longer and, therefore, to do more damage in a field once it has arrived. The wariness of the hoppers, combined with the height of the grass, makes it more difficult to determine the direction of march of a band. Often an observer has no sooner found a band than the locusts have seen him and have started hopping off in a different direction. This makes it difficult to lay a belt of poison bait across the path of an advancing band, a method which works so well with the Desert Locust. Any human activity within the band scatters the locusts and so increases the area that has to be treated. The wariness of the hoppers is sometimes useful in allowing them to be driven, but this operation must be done very slowly and carefully. When frightened the hoppers take cover in dense vegetation and will sometimes hardly move, even if touched. Incomplete control measures or attacks by locust-eating birds may scatter the remaining hoppers, which then become very sluggish. In general, the larger and denser a band is, the more the habitat preferences are masked by activity and gregariousness. There are few

or no records of the total distance that a band of hoppers may march in its lifetime, but a large and active band can certainly cover a number of kilometres. Small incipient bands of phase *transiens* are looser and less active than those of phase *gregaria,* they may move only a few metres in a day while *gregaria* bands may march several hundred metres.

The factors controlling the direction of march of bands of hoppers of the Red, as of other species of locusts, are still not understood. Further work on this subject is needed as forecasts of movements of hopper bands would help greatly in estimating danger to crops and in directing control operations.

(*e*) *Ages of hoppers in bands.*—In big outbreaks, a large swarm may lay eggs in one place one night and then pass on, but more often it will break up into small swarms, which move slowly about and may continue laying for some nights; if the swarms are smaller they move about less at the laying season. In an outbreak area scattered laying is continuous over several weeks. It follows that in a big outbreak the hopper bands contain hoppers all of one age, or differing by a few days only, until bands of different origin amalgamate. In a small or incipient outbreak, on the other hand, the bands are of mixed ages. This is of importance in poison baiting, for hoppers do not eat for a while before moulting. The bands of a small or incipient outbreak will, therefore, never be entirely destroyed by a single baiting, as a proportion of the hoppers will always be moulting and a second application will consequently be necessary. The bigger the outbreak, the easier it will be to avoid this difficulty, by baiting when few or none of the hoppers in a band are moulting.

3. *Adults.*

(*a*) *Young adults.*—When the locusts first become winged, they are soft and weak for several days, only gradually attaining their full hardness and strength. In bands of mixed ages the young adults remain with the hoppers for a while and fly very little. This period is naturally more prolonged in the mixed-age bands of an incipient outbreak than in the one-age bands of a large outbreak. Some of the control methods used against hoppers can also be used, with modifications and rather less success, against the sluggish young adults, so this period has the practical advantage of extending the time available for a hopper campaign.

(*b*) *Transiens swarmlets.*—In the *transiens* phase the Red Locust is rather less gregarious in the adult than in the hopper stage, and the young adults that mature in the smaller bands often scatter and behave like the true solitary phase. Larger groups may retain their integrity. These groups, which may be called swarmlets, spend most of their time settled and indulge only in short partial flights. They never migrate any distance in a body, but merely move slowly about, the area occupied in one day usually overlapping that of the day before. They keep to tall grass, but spread into adjoining short grass in the mornings to feed. Where this tall grass is confined to strips along watercourses or to small patches, it lends itself to insecticidal treatment, but when wide expanses of tall grass are inhabited such treatment is less easy although it is still possible. The sluggishness of the swarmlets makes them easier to deal with than true gregarious swarms, but they may break up and revert to solitary habits during the course of the dry season, especially with the onset of the rains.

(c) *Gregaria swarms*.—The swarms of the gregarious phase are more active than the *transiens* swarmlets and tend to amalgamate rather than to scatter during the earlier part of the dry season. During the latter part of the dry season small swarms in the outbreak area have sometimes broken up and scattered. The usual swarms in the Rukwa outbreak area are small and only rarely do they exceed seven kilometres in length when flying or half a kilometre in diameter when sleeping. Larger swarms are only likely to appear as the result of invasion from outside during the course of a severe outbreak. Such invading swarms may be many miles long.

Whether large or small, Red Locust swarms have definite habits, which differ in some respects from those of some other locusts.

(i) *Daily activity*.—When the locusts of a roosting swarm have become sufficiently warmed by exposing their sides to the sun and by fanning their wings they begin to move. If settled in trees they start to drop down with open wings to the grass below, looking rather like falling leaves. Presently small bunches begin to take short flights from the roosting place to the vegetation around, including even short grass, and active feeding commences. In this way the swarm soon scatters over a considerable area. When it gets hot, flights become more frequent, until a large proportion of the locusts are flying around and settling again. As soon as the majority are flying the swarm starts to move off as a whole. The movement is still mainly circling and low, and many locusts continually settle and feed for a while before taking off again. Eventually a more definite movement in one direction may develop and continue until evening, perhaps with deviations.

The times of the various stages of activity vary with conditions, so that it is difficult to generalise. In general a roosting swarm may be expected to remain settled for from half an hour to two hours after sunrise. Circling flight may become general between mid-morning and early afternoon. A definite migratory flight will not usually start much before 11 a.m. and may never develop at all.

Temperature is perhaps the main factor controlling activity, but more observations are needed.

The swarms in the Rukwa North area in the winter of 1945 seemed to be more active in the bush than on the open flood plain and definite migratory flights would begin at midday or in the early or middle afternoon. On the open plain only indefinite, circling flights would take place during the warmer parts of the day, and more direct flights would only start towards evening, when the wind dropped. It is probable that the wind had a direct effect in discouraging flight and an indirect one by lowering body temperatures.

(ii) *Flight habits*.—During the dry season swarm flights are compact and low, seldom rising above 100 metres in the air. In this respect the Red Locust resembles the African Migratory Locust, *Locusta migratoria migratorioides*, R. & F., and differs from the Desert Locust, *Schistocerca gregaria*, Forsk. This feature makes flying swarms visible from the air, at least in some conditions. It would also make them vulnerable to any insecticide designed to destroy them in flight, such as was tried in 1934 (King, 1934; Internat. Locust Conf., Cairo, 1937, App. 15). The swarms usually fly in a long and narrow column, and at this season flights are very commonly directly or obliquely with the wind, unless deflected by broken country.

With the onset of the rains the flight habits change. The swarms become very diffuse and fly in various directions regardless of the wind. The migrations are also much longer. At the time of egg-laying the swarms often break up into smaller groups that move more slowly again. The individual locusts fly at various heights, varying from near the tops of the grass, or sometimes well above the tree tops, to considerable heights, often to as far as they can be seen from the ground and perhaps higher. They would, therefore, at this season be less vulnerable to aerial attack than in the dry season.

Red Locust swarms have been recorded as flying at night, but, unlike *S. gregaria,* only very rarely. The writer himself has never seen a night flight. Night flights would make scouting and destruction more difficult.

(iii) *Roosting.*—Flying Red Locust swarms usually settle in the evening. Often they settle so late that it is difficult for the boundaries of a settled swarm to be demarcated before dark. In the swarms wandering about Rukwa North in 1945 a good deal of concentration took place after dark, the swarms being much denser at dawn than at dusk. In bush and wooded country swarms usually roost on trees, but in open country they will roost on grass, choosing the taller patches, which may be bowed right down with the weight of the locusts. A roosting swarm occupies only a small proportion of the area that it covers when active and its margins are often sharply marked. If undisturbed a roosting swarm will remain settled densely in this way for a considerable time after sunrise, but will move much earlier if disturbed.

It is doubtful whether the loose, fast-moving swarms preparing to breed ever concentrate so densely for roosting as the dry season swarms. At this time also the high temperatures reduce the nightly period of inactivity.

This habit of concentrating in dense masses for the night lays the swarms open to destructive action, but this has not yet been fully exploited.

As long ago as 1934 successful experiments were carried out in South Africa to kill settled swarms by dusting with sodium arsenite from the air (Naudé, 1934, 1935). The chief disadvantage of the method was that it could only be used in uninhabited territory, owing to the quantity of dangerous poison strewn about the country. Recent discoveries of less dangerous insecticides have led to further trials under the aegis of the British Government with the Desert Locust, which seems, however, to be a less suitable subject, owing to the looseness of its swarms which are less conspicuous both when flying and when settled, and to the longer daily period of activity. At the time of writing only confidential progress reports of some of these experiments are available, so that the results cannot be discussed in detail. When it became evident in 1945 that the Rukwa North outbreak was getting out of hand a request for aircraft was made to enable the young swarms expected to form to be attacked. Unfortunately, no aircraft suitably equipped were available at that time, and consequently many swarms escaped.

Attempts to attack settled swarms from the ground are described later (p. 357), together with suggestions for other methods (p. 368).

(iv) *Egg-laying habits.*—Some locusts, notably the Brown Locust (*Locustana pardalina,* Wlk.) of South Africa, lay themselves open to attack by concentrating for egg-laying on certain spots, where they may stay for several days. Although dense egg deposits in loose soils by large migrating swarms of the Red Locust have been recorded (*e.g.*, Smee, 1936), egg deposits of this species are more commonly difficult to find and are only revealed by the hatching of the hoppers. Faure (1935; Dep. Agric. S. Afr., Inter-State Locust Conf., 1935), in almost the only actual recorded observation of egg-laying Red Locusts, found that the females laid in " hundreds . . . together in small irregular patches varying from one to three feet in length and six inches to a foot or two in breadth ". He noted that the females were easily frightened away even when the abdomens were down in the soil. Egg-laying normally takes place at night, and these tiny dense patches of laying females are never seen by day. In general the swarms of this species break up rather than concentrate for laying. Apart from the tiny patches noted by Faure, the gregarious instinct seems to weaken with the onset of the rains.

Attraction in large numbers to special types of soil for egg-laying is also the exception rather than the rule. Laying has been recorded in a great variety of soils, though with a preference for disturbed or naturally loose types, and for damp places and also for lowland areas, and perhaps especially for open country in these areas (*see* also Queiroz, 1935; Dep. Agric. S. Afr., Inter-State Locust Conf., 1935, p. 89; Internat. Locust Conf., Cairo, 1937, App. 35; Saraiva & Cardoso, 1938; Faure, 1935; Smee, 1936; Mossop, 1933). In the Rukwa outbreak area no selection of special sites has been found, other than an avoidance of unburnt grass (p. 333) and a tendency for breeding to be near the edges of the main flood plains.

It must therefore be concluded that hopes of attacking egg-laying concentrations of Red Locusts, such as are formed by some other species of locusts, are likely to lead to disappointment. Further observations on breeding habits are badly needed, however, and might well reveal some other weakness through which the locust could be attacked.

(*d*) *General conclusion on destruction of adult swarms.*—It is clear that attempts to destroy adult swarms by any method whatever are more likely to be successful during the dry season, and especially in the colder months, than at the beginning of the rains.

Control Methods used in Rukwa.

About 30 years elapsed between the beginnings of the only two recorded major outbreaks of the Red Locust, and so it was thought originally that control operations in the outbreak areas would only have to be undertaken at rare intervals. It was supposed that the close patrolling of these areas would enable swarm formation to be detected at an early stage and the hopper bands attacked while still very small. It was anticipated that the more difficult problem of destroying adult swarms would never arise and, at that time, that poison baiting was by far the best way of killing locusts, both for effectiveness and for economy. It was realised, however, that there were certain difficulties in using arsenical bait in the primitive conditions

of Rukwa, with uncivilised natives, skilled in witchcraft and poisoning, from whom the permanent staff had to be recruited, and with only one European to conduct the campaign as well as to run the whole organisation. It was considered that some of the more primitive methods of control might be equally effective against the small bands which were expected and that they might be easier to work under local conditions. Consequently it was decided to start with a completely open mind and to be prepared to try any method of killing locusts.

Experience soon showed that we had been far too optimistic about the rarity of incipient outbreaks. Although previous work had not suggested such a danger, incipient outbreaks were found to take place every year since the founding of the preventive organisation. It may be that only one outbreak in thirty years or so is successful and inundates half the continent, but at the outbreak area it is impossible to tell which outbreaks will fail to develop. All, therefore, have to be destroyed.

Up to 1944 there was still no reason to believe that any incipient outbreak would give difficulty on account of its size, but in 1945 there was a terrific outburst. Preparations had been made for a considerable campaign, based on previous experience and the density of adults present at the end of 1944. The severity of the outbreak greatly exceeded what the experiences of other years had led us to expect. Help was asked for and supplied by the Tanganyika Government. The campaign was successful in Rukwa South and West and part of Rukwa North, but in the centre of the latter area the situation got out of hand. Somewhere between fifty and a hundred flying swarms matured, although it is estimated that about half the locusts in this central Rukwa North outbreak had already been destroyed in the hopper stage. This large number of swarms bred up despite the fact that not a single real swarm had been present in the previous dry season; there had only been abundant scattered locusts, and one large, sedentary concentration which undertook an occasional mass flight when threatened by grass fire and in the first few days of the rains.

The hope of getting aeroplanes equipped to attack these flying swarms from the air having been disappointed, attempts were made to deal with them from the ground. These were not very successful.

It is therefore now possible to discuss control methods in the outbreak area with considerable and varied experience. Lack of staff has never permitted any real experiments with different methods. The imperative need to kill locusts only permitted the trial of those methods likely to meet with success and others had to be dropped. In spite of this, many useful things have been learnt.

A. Methods used against Hoppers.

1. *Sweeping.*

Sweeping small bands of hoppers with strong entomological sweeping nets has been tried in the Mweru wa Ntipa and Rukwa outbreak areas. In the latter area it was unsuccessful, far fewer hoppers being caught than were scattered and driven down into the shelter of the grass tussocks. Sweeping might perhaps occasionally be useful against clumps of newly hatched hoppers sitting up on soft, short grass, when they are too young to bait and too scattered to beat.

2. *Burning.*

Burning of hopper bands of the Red Locust in dry grass has been practised extensively, chiefly in Uganda. In that country there are two rainy and two dry seasons, so that the grass burning is not as regular as in the lateral tropical belts with one long rainy season and one long dry season. It therefore often happens that hopper bands get into areas with much dry grass left unburnt from the previous season where they can be burnt.

In Rukwa burning usually failed, but there are occasions during dry spells in the rainy season when bands can be destroyed by this method. It is important that the locusts should be surrounded by a complete ring of fire, so that they cannot escape and it is always worth while to carry a box of matches with which to burn any dry grass into which odd bands may have marched. Owing to the scarcity of suitable conditions, burning can never be anything but an auxiliary method, but it need not be despised on that account, being the easiest and cheapest of all methods.

3. *Arsenical spraying.*

(*a*) *Method.*—In 1942-43 some trials of the well-known method of spraying hopper bands with sodium arsenite solution were made. The spraying was done with bucket pumps of the type commonly used in South Africa (Oldfield, 1935), a supply of which had been generously given by the South African Government. A spraying party comprised water carriers, a base, spraying units and scouts. The scouts and operators, and if possible also the poison solution carriers and base men, should be reliable people who can be trusted with poison. The water carriers can be ordinary casual labourers.

The spray solution was made up by putting two tablespoons of sodium arsenite into each debe (a 4-gallon petrol tin) and then filling it two-thirds full of water and stirring well.

The original trials were made on a small scale but, with a fully trained staff and a larger locust outbreak, one European could probably manage a party of the following approximate size in the conditions of the Rukwa area:—

1 European, directing operations generally and handling and measuring solid poison.
6 Scouts.
25 Operators, each with one pump.
35 Poison solution carriers, each with one debe.
4 Base men, to carry boxes of poison when moving and to stir solution, each with one stirring stick.
20 Water carriers, each with 2 debes.

Total—90 men, under 1 European. Equipment—25 pumps, 75 debes.

This number is flexible. It is governed in the first place by the number of operators one European can supervise and keep supplied with poison. In open, short grass country with good visibility the number could, perhaps, be increased as well as that of all the others in proportion, but with small widely scattered bands in tall grass this number would become unwieldy for one supervisor and would have to be reduced. If bands are small, and not to be found within two or three hundred metres of one another, the ground covered in a day increases and the number of scouts must be increased also. More scouts are needed in tall than in short grass, and fewer for large than for small bands. The poison solution carriers must be increased if the bands are small and scattered, and can be reduced if the operators are all working close together on large bands near the base. The water carriers will vary greatly in number according to the distance of the nearest water and, if they have to go far or through bad going, one debe each will be as much as they will be able to carry.

(*b*) *Efficacy.*—Unfortunately the need to go on killing other bands prevented the sprayed bands from being watched as closely as could have been wished, but it is certain that the treated bands mostly disappeared. Surprisingly few dead hoppers were found, but they may have been eaten by ants; some living survivors could sometimes be seen two or three days later in the same vicinity, but no sign was ever found of a sprayed band having marched as a body.

Arsenical spray acts as both a contact and a stomach poison. Hoppers which escape contact with the falling spray are liable to touch it later on the grass or to eat the poisonous grass. After a couple of days the grass dries up and is probably no longer attractive, even if the poison has not already been washed off by rain.

Although the trials in Rukwa were promising, if not absolutely proved to be perfect, this method has been used with such success in the past all over southern Africa that its efficacy is certain. There is no reason to think that it should be less effective in Rukwa.

(*c*) *Advantages and disadvantages.*—The chief advantages of spraying are that it is effective against hoppers at any stage and that it is fairly economical with labour. Its chief disadvantages are the difficulty of keeping the pumps in repair, the danger of poisoning the operators and the time taken up by precautionary measures, the need for European or other reliable supervision and for plenty of water and the extravagance in arsenic.

As regards its effectiveness against all stages, it has the advantage over baiting that it does not depend on the appetite of the locusts, and hoppers at moulting time can also be killed. It is possible that a hopper which moults very soon after being sprayed may throw off the poison, but its new, soft skin would presumably be extra sensitive to any poison drops with which it might come into contact.

The pumps, poison and debes required are well within the carrying capacity of the men needed for the actual work, so that no extra labour is required.

The difficulty of keeping pumps repaired, and particularly of getting rubber tubing in war time, was one reason why this method was not adopted on a larger scale in the Rukwa campaigns. For a large spraying campaign a good stock of pumps and spare parts and a mechanic to do repairs at a central depot would be needed.

Another reason for preferring baiting to spraying was the greater danger of arsenical poisoning in the latter. In baiting the poison solution is diluted by the addition of carrier material. There is more likelihood of the liquid poison used in spraying splashing over the persons of the operators and carriers than there is with the solid poison used in baiting. A certain amount of time is wasted in greasing the hands and forearms of the men handling the poison in the morning, and in washing their persons and clothes at the end of the work (p. 356).

The need for one European to each field party is a disadvantage which is shared by the baiting method.

Another difficulty with spraying is that it requires a good water supply. In the outbreak areas there is often water underfoot, but at other times and in drier country the distance from which water has to be carried may make the method impracticable. Spraying also uses more arsenic than baiting, arsenic in bait going about six times as far as arsenic in spray.

4. *Arsenical baiting.*

(*a*) *Method.*—It has not yet been practicable to set up a central mixing station for preparing bait for the Red Locust outbreak centres and all bait has been mixed in the field. The pros and cons of central mixing and field mixing are discussed below (p. 345).

The field party is organised on the same lines as for spraying, with water carriers, a base, baiters (with or without poison carriers in attendance) and scouts. One debe of bait uses only half the amount of water needed for one debe of spray solution, so that the number of water carriers can be halved.

The bait is prepared by putting one tablespoon of sodium arsenite into each debe, breaking up as far as possible any lumps, adding water up to one-third full, or as much as two-fifths with some bait materials, and stirring till the poison is dissolved. The bait carrier material is then added slowly until the debe is two-thirds full and is well stirred meanwhile to ensure that the whole mass is uniformly wet. The prepared bait should be wet enough for an appreciable amount of water to come out if it is squeezed in the hand.

It was first shown by Coaton in South Africa (Coaton, 1939; Viljoen, 1939; Faure & Jacot-Guillarmod, 1940) that successful baiting of Red Locust hoppers can only be achieved by spreading the bait thinly and evenly and by throwing it forcibly so that it sticks to the grass. Hoppers can sometimes be killed by spreading bait on the ground, as the writer and Mr. W. Allan proved in a test with unsweetened maize meal and wheat bran baits at Chisamba in 1932, but this method has not been found generally successful. In any case, some bait always falls to the ground when thrown on to the grass and so is available to any hopper disposed to eat it.

The bait is thrown hard in half or quarter handfuls with a circular, horizontal, underarm motion. In this way the bait flies apart into small particles, most of which stick to the grass.

Owing to the nervous nature of the Red Locust, bands should be baited as far as possible by throwing the bait from outside. As explained on p. 335, it is seldom possible to destroy a band by laying a belt of poison across its path and small bands are, therefore, usually encircled with bait. If a band is more than some thirty metres in diameter, the baiters have to work through the band itself, an operation that tends to scatter the hoppers. The greater activity of larger bands also makes it necessary to bait a wider belt outside the band. In addition, the older the hoppers are the bigger area they cover. For these reasons it is much more economical in bait and labour to bait the hoppers while still young.

Bait is not much use in short grass, as the hoppers do not stay in it for long but pass on to the nearest tall grass. Baiting is easiest in areas of patchy tall and short grass.

If hoppers have to be baited in continuous dense grass more than about 1·5 metres tall, it is necessary to trample down paths through the grass beforehand. This has to be done in order to give the baiter space to throw, as well as to reduce the amount of poison bait that will be picked up again on his clothes and person. Even with such paths the distance to which bait can be thrown is reduced inside tall grass. The trampling of the paths also frightens the hoppers and takes labour and time. Baiting is, therefore, more difficult and less successful in uniform tall grass than in shorter or more patchy grass. This is

yet another argument for baiting hoppers as early in the season as possible. Extermination while the grass is short is possible in small outbreaks, but work in tall grass is inevitable in large outbreaks, especially in extensive areas of such early-maturing grasses as *Echinochloa pyramidalis,* that occupies most of the Rukwa North outbreak centre. In such conditions the degree of efficiency is unavoidably lower.

The scouts, baiters, mixers and at least one of the men in charge of the bait material should be reliable men. The rest can be ordinary casual labourers.

The party that one European can control under Rukwa conditions is approximately as follows:—

1 European, directing operations generally and handling and measuring solid poison.

6 Scouts.
25 Baiters, each with one debe.
(30 Bait carriers optional, 1 to each baiter and 5 replenishing at base.)
4 Mixers, at base.
4 Men in charge of bait material, at base.
10 Carriers of bait material for moving the base.
10 Water carriers, each with 2 debes.

Total—59 (89 if bait carriers used), under 1 European.

Equipment—50 debes.

It will be noted that, if bait carriers are used, the size of the party is almost the same as that required for spraying, 89 against 90. If bait carriers are dispensed with, the number is much smaller. To keep 25 poison spreaders working, 65 men and one European are needed in a spraying party, and 34 in a baiting party, a distinct advantage to the latter. A baiter can cover rather more ground than a spray operator, but under the system advocated this advantage has to be offset against the time taken by the baiters returning to the base to replenish their debes.

The remarks made above on the flexibility of the numbers of a spraying party according to local conditions apply equally here. The numbers given are for similar average conditions in Rukwa.

When comparing the labour figures for baiting and other methods, it must be remembered that they apply only to the final field operations. Baiting involves great preparations beforehand, a subject which is dealt with more fully below (p. 350).

(*b*) *Efficacy*.—Arsenical baiting, first used on a large scale against the Red Locust in 1936-37 in South Africa (Faure & Jacot-Guillarmod, 1940), is now generally recognised as the most effective method of destruction under conditions in which its use is practicable. In the outbreak areas the first small trials were made in 1942-43 in Rukwa. Its adoption as the sole method is only possible when there is an adequate staff of Europeans or other reliable supervisors.

The number of dead hoppers found after baiting has always been curiously small, but this has been proved to have been at least partly due to the corpses being quickly attacked by small ants (probably *Pheidole*). However, in the earlier tests the bands more or less disappeared and in some instances were definitely known not to have

moved elsewhere. In the final season the results of the use of poison bait were a little disappointing; the bands were very greatly reduced and broken up, but they were never completely exterminated. It appeared that to be annihilated a band would always have to be baited twice. Unfortunately the urgency of destroying hoppers as fast as possible and the shortage of staff prevented any experiments being done to find the best way of baiting under local conditions. It is possible that starting work at dawn would have been better than later in the morning (*see* Coaton, 1939; and also p. 355). Given the opportunity, perfection of baiting in outbreak areas should not be impossible.

Other things being equal, baiting will always be more effective against smaller or scattered bands, which are likely to remain longer in the baited area, than with large, dense, active bands, which may move out of the baited area before all the hoppers have taken poison.

(*c*) *Bait mixing.*

(i) *Wet mixing versus dry mixing in the field.*—An alternative to the wet mixing method described above is to mix the sodium arsenite and bait carrier material dry in bulk on the ground at the start of the day's work, and then to moisten in debes as required. Although dry mixing is quicker, the wet mixing method is preferable, at least in the primitive conditions of the outbreak areas, for the following three reasons.

Firstly, the mixing is better, ensuring uniform bait and uniform results. Sodium arsenite often becomes lumpy and caked hard after storage and cannot then be broken down again into a fine powder. Even if the arsenite is in good condition, it is not possible with hand mixing in the field to ensure that every particle of bait material receives its quota of solid arsenite. If the arsenic is dissolved first, the moistening of the bait automatically distributes the arsenite perfectly.

Secondly, the base is mobile in the wet method and can follow the baiters as they move forward. In the dry method it stays in one place until the bait prepared has been used up, so that more time may be spent by the men walking to and fro between locusts and base replenishing debes. In the wet method the European in charge is in closer touch with his men.

Thirdly, in the dry method, poison is left on the ground in quantities big enough to be picked up by fools, poisoners or witches, and occasionally to be washed in dangerous quantities into rain pools from which drinking water may be taken.

(ii) *Factory mixing versus field mixing.*—Up to date all mixing has been done in the field. This has disadvantages as it takes up a certain amount of time while the debes are being filled for the first time in the morning and uses a little extra labour in the field (four extra in the size of party enumerated above). The most serious objection is that during the mixing a dangerous poison is being used in its most concentrated, solid form under improvised conditions necessitating very close supervision. This means that the European in charge cannot leave the base for more than a short distance and a short time. It is this fact which reduces the size of the party that he can supervise and, therefore, the area that he can deal with in a day. As the number of European supervisors is often the limiting factor in a campaign, and has been absolutely so in Rukwa campaigns to date, this is an important consideration.

On the other hand, factory mixing involves either more labour or else a fairly expensive installation of machinery. The bait material has to be transported to the factory and the prepared bait from there to the field stations, which increases the cost. In any given area the pros and cons of the greater efficiency of field work with previously prepared bait and the greater expense of the factory work must be weighed up according to local conditions. Several small local factories might sometimes be the best solution.

Dry poison bait will keep more or less indefinitely, while unpoisoned bait material is very liable to the ravages of rodents and insects, which is a reason for preparing the bait before a campaign. This applies particularly in an outbreak area like Rukwa, where rats swarm in certain years, and where also our knowledge of the danger spots enables the bait to be stored in advance exactly where it will be needed. Prepared bait left over could be stored for years, if necessary, until another outbreak started, but good stores proof both against the weather and against prying and evil men would have to be built.

An argument which has been urged against the use of a bait factory for the Red Locust outbreak areas is the danger of transporting prepared poison bait for long distances, especially when part of the journey may be made on men's heads. It is true that arsenical bait has been issued in large quantities in some countries packed only in ordinary sacks, and that no accidents have occurred, but the practice can hardly be recommended. To avoid this danger the South African method of packing in special sacks lined with bitumen and strong brown paper is useful. An alternative adopted in the Sudan is to pack the bait first into small cloth bags, each of which holds the exact amount for one debe, and then sew these in sacks. The exact measure in the bags has proved a great convenience in the field.

In factory mixing, the most important consideration is whether wet or dry mixing should be adopted. Although dry mixing has been carried out with great success, it seems logical that bait would be better impregnated by sodium arsenite in solution than by mere admixture with sodium arsenite dust. There should also be less danger of the poison shaking out on a long journey. On the other hand, wet mixing involves the problem of drying the bait before bagging. This is easy enough in climates like those of Egypt and the Sudan but is quite another question in colder and damper countries. The method of mixing must, therefore, be decided by local conditions and the bait material used. The practice of issuing wet bait from a factory must be condemned as dangerous to handlers in transit. It can only be condoned as an emergency measure against an unforeseen invasion, an event which should soon become impossible. At Pretoria the South African Government runs a model factory where maize meal bait is mixed dry; no description of it has been published, but details can doubtless be obtained from the Department of Agriculture and Forestry. This Department presented three of its simple mixing machines to the Red Locust Control Organisation, but it has not yet been possible to use them. Another type of mixer has been figured by Besse (1938).

(*d*) *Bait materials*.—The great problem in baiting is the provision of the base material for the bait. Some of the standard locust bait materials, such as wheat bran, being obtainable at Rukwa only from great distances and at great expense, every effort has been made to find a local substitute. Attention has been given specially to substances which are not used for human consumption. Parts of Rukwa and the neighbouring highlands usually produce a surplus of grain, so that meal can be bought without difficulty; but within the last few years there has been a serious shortage in Rukwa and a famine in central Tanganyika so there might be times when foodstuffs were unobtainable. A waste product should be cheaper than a food.

The following materials have been tried as bases for arsenical bait against hoppers or fliers of the Red Locust in Rukwa. Finger millet meal, maize meal, maize bran, rice polishings, coffee parchment, finger millet malt (" machicha "), finger millet chaff, grass flowers, palm pith and mud have all been tried, while grass chaff has been considered. Lack of staff and the urgency of controlling outbreaks have so far prevented any comparative tests of these different materials. It is, therefore, not possible to describe their relative palatabilities and mortalities caused, except that coffee parchment was only a partial success against hoppers and mud was apparently a failure against fliers, but their availability, cost, texture, ease in mixing and spreading power have been tested and are described below.

It is important that proper experiments on the palatability and killing power of these substances should be undertaken. It must be realised, however, that practicability is just as important as the result of such tests. It may be better to use a slightly less perfect bait material, that is not human food and that can be got cheaply and plentifully on the spot, rather than a perfect one that can only be imported at high cost from a distance, if by spreading the bait more thickly or using a little more arsenic or some other modification a satisfactory kill is obtained.

(i) *Finger millet* (Eleusine coracana) *meal*.—This is the staple food over most of Rukwa and the adjoining highlands. Subject to the results of tests under experimental conditions, it seems to be a perfect bait material. It has been bought for Sh. 1/- or Sh. 1/20 a debe in the more productive areas of Rukwa, but up to Sh. 2/75 in some areas when food is scarce.

(ii) *Maize* (Zea mays) *meal*.—In the north of the Rukwa valley maize is as important or more so than finger millet as a native food. Elsewhere it is a supplementary crop used chiefly to fill in the period of food shortage at the end of the rains before the main finger millet crop comes in. In good years it is obtainable in large quantities from much of the centre of Tanganyika and it appears to be just as good a bait material as finger millet meal. The Rukwa price is the same as for finger millet meal.

(iii) *Maize bran*.—This is obtainable in fair quantity in the north of the Rukwa valley and in small quantities in the centre and south. It is bought by one of the missions for feeding pigs, and in hunger years may be used by the natives for increasing the bulk of their food, otherwise it is thrown away. It is made during the preliminary stamping of the grain in wooden hand mortars. Although it has been used very successfully, the large size of some of the flakes prevents it from being a perfect bait. The

larger pieces fail to stick to the grass and fall to the ground and so are liable to be wasted. In spite of the wastage it still turns out much cheaper in use than the meals as it has been bought at only Sh. -/20 a debe.

(iv) *Rice Polishings* (powdered rice bran).—This substance was supplied by the Tanganyika Government in 1945 when the hopper outbreak became serious. It is a by-product made at a rice mill at Mwaya at the head of Lake Nyasa, where much rice is grown. It has a sale amongst Europeans in the neighbourhood as food for horses, pigs and poultry, but its consistency for bait is not perfect, probably owing to its extreme fineness. It forms almost an emulsion with water, which squeezes out between the fingers so that an appreciable amount is lost when spreading, and further it is not quite as easy to spread evenly on the grass as more granular substances. It needs rather more water than most baits, but it can, nevertheless, be perfectly well used. Owing to the cost of transport it proved to be usually more expensive than the meals, the price being Sh. 1/58 a debe at the nearest end of the Rukwa outbreak area.

(v) *Coffee parchment*.—This is the chief bait material in Kenya, where it is mixed with molasses. Since molasses and other sweetening agencies are difficult to get in the outbreak areas, and Faure and Jacot-Guillarmod (1940) have shown in South Africa that sugar and molasses fail to make arsenical bait more attractive to Red Locust hoppers, the coffee parchment was tested without a sweetening agent. It consists of rather stiff, shiny, curved flakes. Before use it was pounded in a wooden grain mortar to break up the larger flakes, but did not respond well. As feared, it failed to stick at all well to the grass. This was the only vegetable substance tried which definitely failed to give good results, and it was estimated that only about half of the baited hoppers died. It was evident that without the addition of some sticky substance like molasses, coffee parchment is not a suitable bait material for this species of locust. Further trials were dropped.

(vi) *Finger millet malt* (" Machicha ya pombe ya maleze ").—In the Rukwa and Ufipa areas great quantities of finger millet beer are drunk. The grain is sprouted in water and then dried on a mat in the sun. After the beer has been brewed, the residues are thrown away, except that when food is short they may be used to adulterate the scanty meal. These machicha have been found to be a most excellent bait material, having a beery smell which may attract the locusts. The granular texture is ideal for spreading and sticking to the grass and they are rather heavy. The machicha were bought for Sh. -/20 a debe. The quantity obtained was not as much as first hoped for, and they are difficult to collect, as they are made in small amounts at a time by women scattered through the villages. It would not be possible to collect enough machicha to supply a large campaign in Rukwa, but as a supplementary material they are most useful. A disadvantage is that they have to be dried before purchase, otherwise they ferment and rot the storage bags. Machicha of finger millet are probably immune from insect pests, like the whole grain.

(vii) *Finger millet chaff* can be obtained in large quantities when the millet is threshed in the middle of the dry season, which is the best time for laying in a bait supply. One garden can supply from two to six bags. It is a waste product, normally thrown away and burnt, and was first tried in small quantities against adult locusts in 1945. Unfortunately, it contains a certain quantity of the dry pedicels of the millet, stalk-like fragments up to two or three centimetres long, but the actual husks are probably the best material yet tried, as far as mixing and spreading are concerned, and they seem to be palatable. If used in a bait factory it would be worth while to sift out the pedicels, but in field mixing the other advantages of this bait well outweigh the losses caused by these fragments dropping to the ground. The chaff has the advantage of being very light. It was bought at Sh. -/20 a debe or 1/20 a bag.

(viii) *Grass flowers*.—In order to avoid all transport of bait, an attempt was made to collect by hand the flowers of grasses growing on the locust infested plains. A trial was made with *Sporobolus marginatus*, Hochst., which grows pure over large areas in Rukwa, but the collection of the flowers was found to be an impossibly slow process. When mixed up as bait they behaved well as far as mixing and spreading were concerned, but too small a quantity was obtained to see the effect on the locusts. The use of fresh grass flowers as locust bait might be possible in some other region where a grass with larger and soft spikelets occurs.

(ix) *Palm pith*.—A locust officer working in 1945 in Rukwa North, Mr. B. W. Christowitz, when running short of other materials, collected the sawdust-like rotten pith of fallen palm trees (*Hyphaene crinita*, Gaertn., and *Borassus aethiopum*, Mart.). He made bait of this for adult locusts and reported success. Although these palms are common over many of the Rukwa plains, not enough of this product could be obtained for a large campaign, but it could be useful in an emergency for preparing bait on the spot.

(x) *Mud*.—Success having been achieved with such a variety of vegetable baits, it was wondered whether the arsenic rather than the base material was the attraction. Mud is obtained everywhere in a Red Locust outbreak area. An adult swarm was, therefore, treated with mud and sodium arsenite bait, made up just like a vegetable bait. The result was unfortunately negative. The advantage of avoiding all transport of bait material would be so great, that another trial should be made with a mud bait on a hopper band, for the results on a flier swarm of even a bait of known efficacy are very difficult to see.

(xi) *Grass chaff*.—Grass chaff has not actually been tried but should be. If successful it should be considered whether the cost and labour of cutting up green grass with chaff cutters on the spot would not be less than those of buying and transporting other bait materials from a distance.

(*e*) *Advantages and disadvantages*.—The advantages claimed for baiting over other methods are its greater effectiveness and cheapness, the smaller amount of labour needed in the actual operation, and the absence of special equipment. The disadvantages and difficulties are the problem

of supplying bait material, the danger inherent in the use of poison and the consequent need for precautionary measures and of close European supervision, the need for water, the fact that it is not effective against moulting hoppers, and the danger of rain washing the bait off the grass.

As regards the advantages, there is no doubt that killing hoppers by arsenical poisoning is more efficient in respect of the time taken and labour used than any other method yet known. This is particularly true of large scale campaigns. Baiting is better than other ways of poisoning in its somewhat greater speed, the smaller amount of labour needed in the actual baiting operations, and the smaller amount of sodium arsenite used for the same area treated. In addition, no apparatus such as spray pumps is needed, to give trouble. It has also been found the cheapest of all methods of locust destruction in several different countries. Relative costs, however, differ according to local conditions, and the cheapness should not be accepted as universal without due consideration.

Turning to the disadvantages and difficulties of arsenical baiting compared with other methods of locust destruction, the first and greatest is the large amount of bait material required. As an illustration, the estimates for the 1945-46 campaign in Rukwa may be quoted. Of a total of £33,700, the purchase, transport and storage of bait materials accounted for approximately £13,440, and 11 tons of sodium arsenic for £1,100, while the labour estimate was £5,175. Of this £13,440 about £440 were set aside for the purchase of 7,150 bags of local chaff, bran and "machicha" at a cheaper rate, but £4,460 were for the purchase of 850 tons of bait material from outside, mainly cassava and maize meal, and £7,533 for its transport. This item for bait material is a large one, which does not appear at all with other methods of control. Comparing only the labour costs of the different methods of control, it is probable that the extra labour used in transporting the bait to the scene of operations cancels out the saving of labour in the actual operations themselves. Baiting has the great advantage, however, that the bait can be carried in the dry season, so that this extra labour is spread over the months before the campaign, which takes place in the rainy season, at a time when labour may be scarce. The heavy expenditure on the bait item is justified if a proportionately greater efficiency and saving on the other items is effected. Efforts to reduce it by finding suitable cheap, local products have been described in the previous section. It must be noted, however, that local purchase is most useful when the bait is mixed in the field. Much of the advantage is lost, if the materials have to be brought to a central factory for mixing and then carried back again as prepared bait to the field stations.

The danger of poisoning is somewhat less intense with baiting than with spraying, but it exists none the less. It can be minimised if standard precautions are taken, but these take up a certain amount of time out of each working day (*see* p. 355).

With the present-day level of development of the Africans in Rukwa these precautions make it necessary for every baiting party to have one European in charge. Later on, when a thoroughly reliable senior African staff has been built up, it will no doubt be safe to leave a little more to them and to reduce the number of Europeans.

Another disadvantage of baiting is its dependence on water. In this it compares favourably with spraying, which uses more water. Happily water is usually to be found in hollows and channels or even generally underfoot during a hopper campaign in the Rukwa outbreak area, but

there are often occasions when it has to be brought from considerable distances. Such distances of over a mile would be nothing, could vehicles be used, but they greatly decrease the efficiency of the work when the water has to be carried in debes by hand, often through dense, tall grass.

Hoppers will not eat at the time of moulting and a small proportion of a moulting band will, therefore, always escape and have to be baited a second time. As already explained (p. 336), this difficulty applies particularly to outbreak areas, where bands normally contain hoppers of mixed ages.

The last disadvantage of baiting is that rain is liable to wash the bait away before all the hoppers have partaken of it and the area has to be baited again. In very rainy weather even several applications may be necessary. This difficulty is more real with the Red Locust than some others, because it favours countries with a higher rainfall than most species.

5. *Beating.*

(*a*) *Method.*—Hopper beating has been developed to a fine art in Rukwa, and the more senior scouts are already adepts at modifying the method to meet variations in conditions. The labourers are each armed with a suitable stick and divided up into gangs, each with one experienced locust scout in charge as a "capitao", and, if possible, two assistants, of whom one is the second-in-command, or "mnyapara". With very small bands of young hoppers ten to fifteen men in a gang are adequate; with larger bands twenty-five to thirty men are put in a gang, but more than thirty cannot be controlled by one capitao. The whole party, which may comprise up to two or three hundred men, is controlled by a senior locust scout with an assistant, or if possible by a European locust officer with a senior locust scout as assistant. Every mnyapara and labourer has a beating stick about 1·5 to 2 metres long. The best sticks are palm petioles, with the spines trimmed off, as the curved, expanded bases cover a good deal of ground at each blow. If these are unobtainable, any other tough kind of stick can be used, provided it is cut with a broad, curved tip.

The work is done in three stages, scouting, concentrating and beating.

(i) *Scouting.*—The scouting is done by the whole labour force advancing in extended line in a fixed direction. On a locust band being found, one or more bands stops to deal with it, according to the size of the band. After destroying the band, the men deploy again and continue in the original direction.

In a heavy outbreak, when the hopper bands are large and close together, it is better to have a few men out scouting the whole time while the labour beats, as with baiting and spraying. The beaters then go straight from band to band. With numerous large bands too much time is wasted if the labour gangs are deployed into line again after every beating.

(ii) *Concentrating.*—Beating locusts is hard work, so it is necessary to reduce the area to be beaten as much as possible. For this reason every band is concentrated before beating. This work must be done carefully and slowly, otherwise many of the hoppers will take cover in the grass tussocks, instead of moving towards

the centre of the band, and will afterwards escape. As soon as a band is found, the capitao or capitaos concerned form their men in a ring round it. The mnyapara then starts to lead the ring round and round, slowly drawing in on the centre of the band in a close spiral. Every man tramples the grass inwards towards the centre and sweeps inwards with his beating stick at the grass still standing within the ring. When this is done properly, the sight of the moving men and the disturbances of the grass frightens the hoppers from the edges of the band towards the centre. When the capitao sees, either that the outside hoppers are too tired to hop any further and are diving into the grass tussocks, or that the concentrated mass is so dense and active that any further circling will make it break out between the men's legs, he gives the order to stop.

Two modifications of this standard method must be noted. Firstly, extensive bands are usually cut into several groups, which are dealt with separately. A band is cut where it is narrow, or where the grass is shortest, as the hoppers are moved more easily out of shorter grass. The size of the groups into which a large band is cut depends on the density and size of the hoppers. A dense group of large hoppers can be concentrated into a beatable area from a radius of twenty or twenty-five metres, on the other hand younger and especially more scattered hoppers can only be driven for two or three metres. A loose band of younger hoppers, therefore, has to be divided into a larger number of smaller groups. In the former case several capitaos would join forces; in the latter they would work separately.

The second modification is used when the grass is too tall and tough for the spiralling round to be easy. Then the men are allowed to stand in a ring round the band facing inwards, sweeping at the grass in front of them and converging slowly step by step until the band is sufficiently concentrated. This is less efficient, as there is only the movements of the sticks and grass to frighten the hoppers inwards, and little movement of the men themselves.

(iii) *Beating.*—When the band is sufficiently concentrated, the men face inwards and beat the grass and the hoppers, starting from the outside and working slowly inwards, until the band is exterminated. The best results are obtained by making the men beat to their own threshing chanties.

If the grass is flooded, beating is only continued until the grass is all knocked down into the water, whereupon the work is continued by trampling, also to song. This method is not as efficient as beating on unflooded ground; if the water is more than 20 centimetres deep it is of little use, and it is best to drive the band away from the deeper water.

If the grass is very tough, one or two men with slashing knives are introduced into the ring of beaters, once the grass has been beaten down, to cut the bigger stems. If this is not done, a fair proportion of the hoppers sheltering in the beaten grass are protected from being crushed by the resilience of these strong stems.

(iv) *Treatment of bands of mixed hoppers and adults.*—Even when the hopper bands are becoming adult it is possible to continue beating for a few more days by a different method. The adults are too active to be concentrated in the way used for hoppers, so this part of the process is dropped. Every man is armed with a tough, twiggy stick besides his beating stick. When a mixed band is found, a ring is formed round it and, on the capitao's word, the men run inwards towards the centre slashing with their branched sticks at the winged locusts in the air and on the grass until they are knocked down. Then the men reform their ring and beat fliers and hoppers together in the usual way. If no hoppers are left, it may still be worth while to slash at the fliers with the branching sticks alone. Being still soft, many will be maimed, even though few are killed. When only slashing at adults is done without beating, many bands or swarmlets can be attacked in a short time. This method becomes impracticable once the fliers become a little strong on the wing.

This is not an efficient method, for the hoppers are scattered by the initial manoeuvre, and some fliers get away. It is only mentioned as a way of continuing the war against locusts that might otherwise escape. If baiting is practicable, it is to be recommended as the only really efficient method at this stage.

(*b*) *Efficacy.*—As mentioned above, when the control organisation was first started, it was thought that beating was an extremely primitive and ineffective method. Its use for three years as the main method of control in Rukwa has been enforced by the lack of reliable staff. This was due to the campaigns being waged during the war, when European help was unobtainable, and at a time when the organisation was in its infancy and its African staff still not fully trained. The result has been an entire change of opinion about the efficacy of the method. During the three years in which it has been used several small and moderate-sized incipient outbreaks have been entirely controlled by beating alone and others by beating aided by a certain amount of poisoning. Only one outbreak got out of hand, the Rukwa North 1945 outbreak, but this developed so fast and on such an unprecedented scale that it would certainly have overcome such resources as were available to deal with it at that time, whatever method had been used. Over a third of the bands that developed during that outbreak were destroyed by beating, which was even more successful than it had been with the smaller and looser bands of previous years.

It is clear that beating is not such an archaic and futile method as is sometimes believed. While it is not claimed that it is the quickest or cheapest method, it has been proved that small and moderate sized bands of the highest density can be destroyed as completely as by any other method. When labour is abundant but other resources limited, the conduct of a Red Locust campaign partly or entirely by beating is well justified.

Beating is most effective against small but dense bands. Such bands can be surrounded by a single ring of beaters, concentrated, and beaten almost to complete extermination. Their activity, which aids concentration and, therefore, favours the beating method, is a disadvantage for baiting as the bands are more likely to move out of the baited area before all the hoppers have taken poison. Loose bands, on the other hand, are definitely better treated by bait than by beating. The more scattered hoppers are less active and less easily concentrated into a small area for beating. For the same reason they are more likely to remain

in one spot and to take any bait that has been put there. Very large bands, such as are formed from the progeny of migrating swarms at the height of an invasion, are not easily beaten. In the first place labour is seldom available in large enough quantities to beat such bands, and secondly, the cutting up of very large bands into groups small enough to beat would cause a good deal of scattering of stragglers, which would be difficult to destroy afterwards.

Beating is also less effective than usual in grass which is thin underneath. When there is little cover near the ground the hoppers try to escape between the sticks of the converging beaters, instead of lying hidden in the mass of beaten grass until they are completely crushed. In Rukwa this applies chiefly to *Sporobolus robustus*, Kunth, a large grass dominant over considerable stretches in the southern half of the outbreak area.

(c) *Advantages and disadvantages*.—The advantages are, a minimum of trained native staff, no equipment to go wrong, no accessory work outside the actual control measures, no water needed, very efficient scouting and less European supervision required than for any other method. The great disadvantage is that it requires a large labour force, also it is hard work and it loses its efficiency on flooded ground, in grass without much ground cover and with maturing bands.

The reduced amount of European supervision required is important, for suitable men are expensive and often unobtainable. A campaign in the Rukwa outbreak area by beating alone could be run by one locust officer in each of the four areas into which the valley is divided for locust control purposes, but to run one of the same magnitude with poisoning a locust officer would be needed at each of the sixteen stations, apart from the work of collecting a bait supply in the previous dry season. Although a locust officer supervising a beating campaign cannot be everywhere at once, he can look after the work easily in a large area, because every patch of grass beaten stays visible for months after, making it impossible for the locust scouts in charge to give false reports of the work done.

The small number of trained natives needed is an advantage which is apparent mainly when the bands are large and numerous. According to the average figures given above, a spraying party under one European would contain 90 men, of whom at least 31 and preferably up to 70 should be at least reliable and if possible trained locust scouts. A baiting party under one European would consist of about 59 men (if no bait carriers were used), of whom 36 should be scouts. On the other hand a beating party of up to 200 men can be managed by one senior locust scout with a minimum of 15 and at the very most 62 scouts to help.* It is believed that three parties so composed would be of equal efficiency under normal conditions.

The lack of equipment contrasts particularly with spraying and the absence of accessory work, apart from the actual control measures, contrasts very favourably with the baiting method. When comparing

* Using a capitao, mnyapara and third scout, *i.e.*, three scouts, for each gang, a party of 200 beaters could be divided up into 20 gangs of 10 men each for attacking very small hopper bands; these would need $3 \times 20 = 60$ scouts, plus 2 assistants to the senior locust scout, total 62 scouts. For larger bands the gangs could have 20 men each, and the figure would be $3 \times 10 + 1 = 31$. For still larger bands the gangs could contain the maximum of 30 men each, and the figure would be $3 \times 7 + 1 = 22$. If the third scout for each gang were dispensed with, the corresponding figures would be: for 20 gangs of 10 men each, $2 \times 20 + 2 = 42$; for 10 gangs of 20 men each, $2 \times 10 + 1 = 21$; for 7 gangs of nearly 30 men each, $2 \times 7 + 1 = 15$.

the figures for labour and for trained native and European supervision just given, it must be remembered that these apply only to the actual field operations. For a bait campaign great preparations have to be made beforehand (p. 350).

It has already been explained that both spraying and baiting depend on a handy supply of water. If water has to be carried from a distance, where wheeled transport cannot be used, the labour required is considerably increased and no longer compares so well with that used in beating. In the latter case the only water needed is small quantities for drinking which is easily carried in the gourds that some of the men can carry slung on their girdles.

In beating the scouting is normally done by the entire labour force strung out in line, so that the whole area is combed very thoroughly. The poisoning parties described above have been enumerated with about six scouts to each party, the rest of the party being too occupied with their own loads to be able to scout as well. It is manifestly impossible for such scouting to be as efficient as that done by a complete line of men. Such complete scouting is specially useful in the early stages of a campaign, while the little hoppers are still dotted about in numerous small bands. Provision for more complete scouting in a poisoning campaign immediately raises the labour estimate again and so reduces the advantage over beating.

Turning now to the disadvantages, the first and great one is the large labour force needed. The partial failure of the 1944-45 Rukwa campaign may be ascribed largely to shortage of labour, but it is considered that, if the severity of the impending outbreak could have been correctly estimated two or three months before, it would have been possible to get enough labour to suppress it by beating alone if necessary. On the other hand, an outbreak of the severity of that in part of the Rukwa area in 1944-45 would be beyond the power of any locally available labour to control. It is, therefore, necessary to make provision for the use of other methods in Rukwa as well as or instead of beating.

Beating locusts is unquestionably hard work, but both men and boys have been able to work long hours without ill effects, in spite of the fairly severe Rukwa climate. It is doubtful if it is harder work than carrying water in debes, but it is more tiring than most of the other operations involved in baiting and spraying. The work is most exhausting when bands are large and numerous, as most of the time is spent in actual beating in long spells. When bands are smaller and more scattered, the alternating spells of scouting, concentrating and beating give relief.

The disadvantages of the use of beating on flooded ground, in grass thin underneath and against maturing bands have already been dealt with when describing the methods of beating.

6. *Hours of work.*

In South Africa baiting has been found to be most successful in the night, early morning and evening, when the hoppers are more concentrated and less active (Coaton, 1939; Viljoen, 1939). Spraying and beating should also be most effective then, for the same reasons. In the more humid regions, where most of the outbreak areas of the Red Locust lie, most of the rain falls in the evening and first part of the night. This makes work at these times more difficult and may often make poisoning ineffective. Local conditions in Rukwa, of which one of the principal is the distance of possible camp sites from many of the places where hopper bands

occurred, have compelled the adoption of the technically less suitable system of working throughout the middle of the day. Work at night was also impracticable owing to the impossibility of controlling a large labour force in long grass in the dark, the prevalence of lions, and the hordes of mosquitos. These difficulties would also exist in certain other areas where a Red Locust campaign might have to be waged.

7. *Precautions taken when using sodium arsenite.*

When using sodium arsenite for locust destruction in Rukwa, the following facts have always been taken into account. Sodium arsenite is a deadly poison; the local natives drink from isolated pools and channels when out on the plains; poisoners and witches are still rife and might steal the poison if given a chance; the African is apt to be forgetful and careless if not watched, and even the permanent locust scouts are still far from being an entirely reliable force of men. For these reasons the poison has been stored under supervision and has only been used in the field under the eye of a European.

Under Central African conditions it is necessary to watch continually to ensure that poison does not find its way to the mouths of the operators, either directly or through drinking vessels, and that clothing, persons or skin wounds do not become contaminated. In order to prevent absorption of arsenic through the skin, the exposed parts of the operators have been greased with a preparation, of which the prescription, kindly supplied by the South African Department of Agriculture and Forests, is as follows:—

The cream for arsenical dermatitis

Acid carbolic	5 grains.
Zinc oxide	6 drachms.
Lanoline	2 drachms.
Olive oil	1 oz.
Aqua calcis	1 oz.

This is expensive to use on a large scale, and ordinary vaseline seems to work quite well, while the cream can be kept for actual cases of dermatitis.

Operations in the field are carried out in such a way as to reduce contamination of the workers to a minimum. At the end of a day's work all those who have handled poison have to wash carefully, and a finger nail inspection afterwards reduces the risk of accidents.

The very wet bait which has to be used for this species of locust makes the finger tips very sore after a few days continual handling, so that it is best to rotate operators between poisonous and non-poisonous tasks.

A dose of arsenic antidote is carried by every party. With care and common sense the dangers of arsenical poisoning can be reduced to a minimum even in the primitive and difficult conditions of the outbreak areas of the Red Locust, but the time and European supervision required for these precautions are a serious handicap. The discovery of a locust poison harmless or even less dangerous to human beings would make locust control very much easier, especially in backward areas. It is of the first importance that efforts to find a substitute should continue.

B. Methods used against Adults.

The present position of Red Locust control is, that the insect can only really be attacked successfully during the two or three months of hopper life; for the nine to eleven months of adult life it is nearly immune. The egg stage is also safe, except during big invasions (pp. 334, 339). Since communications are difficult in the breeding season, especially in the swampy outbreak areas, and labour also is scarce owing to agricultural work at that time, it is most important that some way of attacking the adults should be developed.

Up to 1945 only hoppers had been attacked in the outbreak areas, but when it became apparent early in that year that some hopper bands would escape destruction and form flying swarms, an attempt was made to obtain the help of aircraft equipped with poison dusting apparatus. When aircraft could not be obtained, the swarms were attacked from the ground. This campaign cannot be said to have been a complete failure, because large numbers of locusts were destroyed, but far more escaped. Experience so far indicates that the use of ground methods of attack against Red Locust fliers is an expensive and inefficient supplement to other methods only worth using in times of necessity. Since control from the ground has been used successfully against adults of some other species of locusts and is still being recommended in certain quarters for the Red Locust, the Rukwa experiences will be discussed below in the hope that they may be useful to future practice and policy.

1. *Poison dusting.*

It had long been considered that the habit of concentrating in patches of tall grass, especially in the latter part of the dry season (*see* pp. 332, 336), would lay the adult locusts in the outbreak areas open to being attacked with poison dust guns. Accordingly, in 1941 a few Barlow Powder Pumps (kindly given by the South African Government; *see* Oldfield, 1935) and Hudson Dusters were obtained. The original intention of using these machines with sodium arsenite dust was not carried out owing to the caked condition of much of the arsenic stock and for other reasons. In March, 1945, a small trial using dinitro-ortho-cresol was carried out by Mr. H. J. Brédo in company with the writer against a mixed band of young adults and young hoppers in fairly tall, tangled vegetation at the edge of the Rukwa West flood plain at Milepa.

The results were negative. It is understood that dinitro-ortho-cresol has given very variable results against locusts, and it is possible that under different conditions of humidity and other factors it might have proved more satisfactory.

Of the machines used, the Barlow pumps were found to be too small for large scale work, while the Hudson dusters were flimsy and fragile. Both kinds of machine discharged poison in all directions and would not be safe to use on a large scale with African staff. The Barlow pump shoots the powder forcibly through a tube, but the force of the jet is spent at less than a metre. The Hudson duster has an extension pipe some three metres long, but the dust cloud comes out of the nozzle without force. With both machines, therefore, wind has to be relied on to carry the cloud across the locusts. On the occasion of this trial a fair wind was blowing and took a good cloud to a distance of 30 metres or more, some of it too high in the air, but mostly amongst the settled locusts. In order to get at the locusts several parallel paths were trampled through the vegetation across the line of the wind. The impression was gained that to dust locusts thoroughly with these machines the paths should not be more than 20 metres apart.

Happily a fairly steady breeze from the south-east blows over Rukwa and neighbouring regions for most of the dry season, giving good conditions for dusting. Although both the insecticide and the machines tried proved unsatisfactory, it is still felt that dusting of adults is worth a further trial. What is needed is some large, powerful, strongly built machine mounted on a sturdy motor lorry with a second lorry for carrying spare poison and personnel. Such dusting units could operate on the flood plains in the latter part of the dry season, after the grass was burnt against *transiens* swarmlets and *solitaria* concentrations. They could do good work in Rukwa South and West, where the grass is more patchy, but perhaps not in Rukwa North, which is mainly a uniform expanse of tall swamp grass.

2. *Arsenical baiting.*

Baiting was done in Rukwa North in the winter of 1945, having first been tried with some success against the one or two small, young swarms which had escaped the hopper campaign in Rukwa West.

(*a*) *Method.*—This was the same as that described above (p. 343) for hoppers, with the following modifications caused by the activity and powers of flight of the adults.

The scouting was done in the afternoons and moving swarms were tracked to their sleeping places, where they were attacked at dawn the next morning.

On account of the flight habits of the swarms (p. 337), all the bait had to be spread early in the day. Camp was left in the dark and work started on the swarm as soon as it was light enough to see properly. If beating was being used on part of the same swarm, all hands were started off on beating and then those needed were removed after an hour or so to start baiting. Only a few hours were available for the work, as the bait had to be applied before the swarm scattered for feeding, to give the locusts time to take it before flying right away. The water supply became increasingly difficult as the swamp pools and channels dried up; in one or two places it was later obtained by digging wells but a swarm far from water could not be baited.

The poison was at first mixed a good deal stronger than for hoppers. This gave a satisfactory kill, and later the concentration was reduced to one only slightly stronger than that used for hoppers.

Owing to the wide area over which swarms scatter for feeding in the morning, bait has to be spread over a relatively far wider area than for a hopper band of the same size. Very small swarms were encircled by bait, but with larger ones bait was sometimes scattered in strips through the swarm, a procedure that frightened many of the locusts away. On other occasions it was spread over an area to one side of the swarm, which was either left to find it itself, or else was driven towards the poison by the whole labour force advancing slowly in extended line. This driving sometimes worked quite well but at other times was a complete failure so that the day's work was wasted.

(*b*) *Efficacy.*—In South Africa the early tests of baiting adults suggested that the method would probably be successful in special conditions, such as small swarms, open savannah bush country, plenty of good roads and cool winter weather (Faure & de Villiers, 1937). The results of the Rukwa trials are described below.

(i) *Mortality.*—It is not easy to assess the value of poisoning by arsenic on adult locust swarms because the poison acts slowly and the locusts usually fly away from the place where they were treated.

Some dying and dead individuals could usually be found in the baited areas, the corpses being scattered at intervals of about 0·3 to several metres apart. On one occasion, when they were lying at intervals of about 0·3 to 1 metre a careful search by the writer with three scouts showed that they could be picked up at the rate of about 100 per man per hour. Sometimes they lay rather more thickly over small areas, some only a few centimetres apart or even touching. In the densest kill seen the writer was able to find after careful search six corpses close enough together

to be covered by his outstretched hand and fingers. Both the swarms just mentioned had settled again for the night partly on the baited area. Corpses in appreciable numbers were confined to the baited areas and up to a few metres away. Most of these were soon attacked by small ants (*Pheidole?*), but they were probably never completely destroyed like the hoppers (pp. 342 and 344). Even in the highest kill, the density of the corpses was far less than that of the living locusts had been, so that it was clear that only a very small proportion of the swarm died on the spot.

Most of the baited swarms flew too far away for the later effect of the poison to be seen, but in a few instances it was possible to learn more. During the campaign one or two dead or dying locusts showing symptoms of arsenical poisoning were found in the line of flight of a swarm. They had presumably dropped out from the swarm while migrating. On one occasion a single moribund locust with arsenical poisoning symptoms was found in a fresh swarm before baiting was finished and only some four or five hours after it had started.

The swarm already mentioned as providing about 100 corpses per man-hour on the baited site was baited on 28th April. During the day the locusts scattered a good deal and circled, but the swarm never took to flight as a whole, and in the evening it settled again partly on the baited area. The scouts watching it in the evening found three corpses. On the second day it took scattered and partial flights in various directions, but in the middle afternoon it flew off north-north-east for a couple of kilometres, leaving behind numerous stragglers in the baited area, where corpses were to be found in considerable numbers by the evening. On the third day the count already mentioned was made on the baited area, while scouts continued to follow the swarm itself. In the middle of the day it was reported to be scattered and circling not very far from the original baited site, with many very sick individuals and dead scattered at about one every two metres. By the afternoon it was further north, scattered, and only two corpses were found, and in the evening the writer found it settled moderately densely. The following morning, 1st May, three full days after being baited, the writer re-visited it at its sleeping place and found it more concentrated. After twenty minutes' careful search where the locusts had slept most densely no corpses could be found and the morning watchers only found two dead and two dying after much careful searching. This swarm then remained apparently healthy until on 3rd May it joined another, which was again attacked. It appears from this series of observations and others given below, that most deaths take place on the second and third day and few thereafter.

Another swarm was baited on the morning of 3rd June. At 4.30 in the afternoon sickly and dead individuals were found to be scattered about commonly in parts of the baited area. Meanwhile, the swarm had moved about two kilometres north-west, where it was attacked by beating on the second morning. By the afternoon of the second day it had moved on again, but sick and dead locusts were scattered over and near the sleeping

place much more commonly than they had been on the first afternoon at the baited site. In the evening the swarm joined another and flew away.

Only in a single instance did a swarm after baiting look appreciably smaller than the same swarm before treatment. This was a very small swarm, which it was possible to bait on 5th June more completely and quickly than any other. It slept the first night partly on the baited site and hung around the same area, but not actually on the baited place, until the afternoon of 8th June when it moved away with another swarm. It had picked up additional bait from a further site the day before it was baited itself.

(ii) *Length of time for which bait remains effective.*—This last point raises the question of the length of time for which bait remains effective. The swarm just mentioned flew slowly, circling and settling on 4th June through the grass baited on 3rd June. Quite early on the morning of the 5th, during the baiting of this swarm, two locusts were found already dying with black diarrhoea. There had not been time for that morning's poison to act so quickly, and it was clear that they had picked up poison a day old the day before.

Another swarm on 31st May moved slowly with much settling through the area baited on the 28th. On the following morning a lot of fresh corpses were present in this area. The bait still smelt quite strongly.

On 19th May a rather unsatisfactory baiting had been carried out. A few dead were found in a hurried inspection by scouts on the evening of the 20th, and on the 21st only rather sparsely scattered active adults but many sick and dead, some of the corpses being fresh and some dry. On the 22nd there had evidently been an incursion of healthy locusts from outside, and there were additional fresh corpses and sick individuals. These may have been remnants of the original swarm dying slowly, or they may have been some of the fresh locusts being poisoned by the stale bait. The area was not re-visited until the 29th, when an attack was made against another swarm, which slept partly on this area baited on the 19th. In the middle of the day this old baited area was inspected again, to see if any of the new locusts showed signs of poisoning. No sickly or very freshly dead locusts could be found, but there were some corpses which looked only two or three days old, that is to say the locusts may have died as much as seven or eight days after the poison was first laid.

Another piece of evidence refers to a swarm which was never deliberately baited at all. On 7th June a fairly large swarm came north-west out of the main flood plain and was joined by two smaller swarms at the edge of the trees, into which the locusts moved and rested for the night a little way in. The main swarm passed near and very likely actually through the area just mentioned, which was baited on 19th May, 19 days before, and the one baited on the 29th, nine days before. One of the smaller swarms was a tiny one and came from the north-east along the edge of the main flood plain. It might have come in contact with the bait laid in that direction on 28th May and 1st June, ten

and six days earlier respectively. The third swarm was a fairly small one which appeared at the edge of the flood plain near where the big swarm reached the trees. It may have settled on the bait laid in the vicinity on 29th May, nine days earlier. It was probably an offshoot of a composite swarm which had been beaten that morning a couple of kilometres further west, and one of whose two components may possibly have slept the night of the 5th partly on an area baited on 24th May. The most recent bait with which any part of this composite swarm could have come in contact on or before 7th June was, therefore, six days old, and the most likely sources of poisoning were respectively nine and nineteen days old. On 8th May the swarm was watched and found to split into three main parts, which circled around and moved slightly inland. One part revisited the neighbourhood of the bait areas of 28th May and 1st June and may, perhaps, have partaken of the poison, by then twelve and eight days old respectively. The others did not go near any baited areas. On the 9th the nearest to camp of the three swarms, into which the big one had split, contained many dead and dying locusts with symptoms of arsenical poisoning. In the evening, after various evolutions, it met another swarm and joined up with yet another which had been treated that morning, so that no further evidence could be obtained.

As already mentioned, two swarms appeared on 5th June and joined up on the 6th, after one of them had been beaten in the morning. On the 7th the combined swarm was again beaten, and for the night of the 7th it settled partly in the area baited on the 3rd. On the 8th it was again beaten, but the part in the old baited area was left undisturbed. On the morning of the 9th, when it was again attacked by both beating and baiting, plenty of locusts could be found already dead and dying. Some were under the baited grass where they had slept densely on the night of the 7th, but more were under the bushes where they had spent the following night. These locusts, therefore, definitely took and succumbed to poison four and a half days old.

From these observations it is clear that adult Red Locusts can be poisoned by bait which has been spread at least several days before, although it has been dried out by the sun. It remains to be seen if it is actually eaten dry, or if it absorbs dew and becomes palatable only when moist in the night and early morning. Since sodium arsenite bait scorches the grass, so that it dries up within two or three days, it seems likely that the condition of the carrying foliage may not matter. However, experiments on the attractiveness of bait on, and in competition with, foliage in varying degrees of freshness are needed if adult baiting technique is to be perfected.

(c) *Symptoms of arsenical poisoning in adults*.—The first symptom of poisoning by arsenical bait is a loss of alertness, the locusts can fly but are not flushed as readily as usual. Later the wings become paralysed, and on disturbance the locusts hop actively but cannot open their wings or fly. Finally, they become sluggish and die, usually on grass or trees but soon drop to the ground.

In the earlier stages a dark brown diarrhoea can be squeezed from their abdomens, instead of the usual hard faecal pellets, but later the

abdomens feel emptier than those of normal locusts. Dead or nearly dead locusts usually have a blackish brown lump of congealed diarrhoea stuck round their tails. This dark brown diarrhoea is probably not an infallible test for arsenic and can apparently be caused by some other sickness (Allan, W., Annex 1 to King, 1934).

(*d*) *Difficulties*.—There is no difficulty in inducing adult Red Locusts to take sodium arsenite bait, if they can find it; the great trouble is to present the bait to them, on account of their mobility. With swarms migrating rapidly across wide stretches of country this difficulty would usually prevent a campaign based on ground baiting of adults from being successful. Such a campaign could only be attempted in either a thickly inhabited country with good communications or where the swarms circle slowly around for weeks at a time, or a country where they are known to follow certain lines of flight, along which preparations could be made in readiness for the oncoming swarms. Such areas as Natal, southern Portuguese East Africa and Ruanda fulfil both the first two conditions, the southern highlands of Nyasaland and the Rukwa North outbreak centre the second, and the third is fulfilled by the western corner of this outbreak centre, where most of the emigrating swarms follow the Kavuu swamp.

Having found where a swarm is roosting, the bait and personnel have to be assembled by dawn the next morning. It is impossible to ensure that all the locusts eat bait because, as with the hopper stage (Coaton, 1939), the fliers do not seem to be attracted to the bait, but only to eat it when they happen to find it. It is, therefore, necessary to spread the bait over as wide an area as possible around the swarm. When feeding in the morning a swarm covers many times the area that it does when roosting. The bait should be spread over an even larger area, as it cannot usually be foretold in what directions the swarm will spread in the morning. This large expanse must be baited well before the swarm starts flying away, and if possible before it starts scattering at all, in order to give all the locusts a chance to find poison. Work by moonlight might sometimes be possible. To cover so much ground in such a short time necessitates a large staff and a plentiful supply of bait, all to be very mobile. This is expensive and in little developed areas may be impracticable, and as has already been pointed out, lack of water may limit the use of this method.

Baiting trials were made in open grassland and grassland with few scattered trees and bushes, with most of the locusts roosting on the taller grass; in the escarpment-foot bush of Rukwa, with its terrific jungle of giant grass, it appeared impracticable. In bush country with short grass baiting might be more successful than in open country as the locusts would roost on the trees, underneath which the bait could be spread on the grass, and many of the locusts would come down and feed. In bush country where the grass had been burnt off this would not be possible and if the trees were tall, probably nothing could be done. If there were short trees and bushes, the bait could be thrown upon the foliage. It is not known whether locusts will eat bait on unpalatable as well as palatable tree leaves, but the Red Locust shows marked preferences in its choice of such leaves.

The difficulties and expense involved in the provision of bait, in the use of a poison dangerous to human beings and in the need for European or other reliable supervision have already been noted in detail when referring to hoppers (p. 349). They apply more forcibly to an adult campaign owing to its much greater extravagance in men and materials.

3. *Hand catching.*

The natives of many parts of Africa, including Rukwa, catch Red Locusts, which they dry and eat as they will their dried fish or meat. They go out at night or in the early morning, when the locusts are sluggish, catch them by hand and stuff them into pots or gourds. Large numbers are often caught in this way but the proportion of the whole swarm killed is certainly usually small. One very small swarm which moved out of the outbreak area in 1945 was said to have been destroyed and broken up by this method by the natives of Rungwa. It is possible that swarms are sometimes exterminated in this way in thickly inhabited hill country, where swarms move slowly round about and can be attacked several days running by the natives. As a rule the natives need no encouragement to catch locusts for food. At one time in Rukwa North in 1945 they did become satiated and were then offered pay for catching them in the same way, but the response was poor. Hand catching is mentioned again below as a supplement to the next method.

4. *Beating.*

When the destruction of adult swarms from the ground was first considered, their habit of roosting in dense patches on the grass at night at once suggested that they might be beaten like hoppers. Although locust officers have reported good results from this method on occasions, the writer's own experiences have not been encouraging.

(*a*) *Method.*—Beating can only be used against locusts roosting on grass, not on trees. It has been used both in the open flood plain and in the scarp-foot bush, in parts of which the trees are scattered and many of the locusts roost on the giant grass.

The scouting is done on the day before as for baiting. A large labour gang is necessary, the larger the better for anything except a tiny swarm. The scout who marked the swarm leads the party to the roosting swarm in the dark or at dawn, as early as it is possible to see to work. The men are lined up at one short pace apart on one side of the swarm, or of as much of it as can be dealt with. On the word being given, they advance fairly quickly through the grass, breaking it down and knocking the roosting locusts down. If the grass is very tall, tough or tangled, it is better for the men to hold their sticks horizontally, join sticks with their hands and press down the grass with them, trampling it down further as they advance. If the grass is less severe, the men beat it down with their beating sticks, an oblique blow being more effective than a vertical one. The object of moving quickly through the grass at first is to prevent the locusts from getting warmed up on top of the grass and flying off. They do this less readily from inside the grass. The men are moved backwards and forwards at this moderate pace, until the grass is all beaten flat.

If the locusts are alert and start fanning their wings on top of the grass preparatory to flying off, it is sometimes better to run even faster back and forth at first, slashing horizontally at the locusts rather than at the grass, in order to knock them down and wound some. As soon as the grass is beaten flat, the men are reformed into a regular line and made to walk in line abreast slowly back and forth across the flattened area, beating at the grass and the locusts under it with their beating sticks, to the time of their songs. This work goes on for a few hours, with such rests as may be necessary, until there are no undamaged locusts left.

As the sun gets up, undamaged locusts start coming up out of the beaten grass, sitting on it, fanning their wings and flying off. They are discouraged from doing this if people are moving about treading on the grass. In uninhabited country it is necessary at this stage to detach a few beaters to keep walking all over the beaten area away from the main line of beaters and to beat at every locust they see come up from the grass; in inhabited country it is much better to encourage the local women and children to come and collect the locusts under the grass by hand. If present in sufficient numbers and kept moving over the whole beaten area, these local inhabitants can be a great help and may catch as many locusts as are killed by the sticks of the beaters.

It is too exhausting to keep on beating continuously without a rest, so the work is interrupted from time to time. The beaters are scattered over the whole beaten area and made to turn over the grass and collect by hand sheltering locusts, looking particularly in any hollows or under extra tough grass, where they are least likely to be crushed by the beating sticks. They are told to ignore dead locusts but to catch and behead any still living.

(*b*) *Efficacy*.—The results of beating were disappointing on account of the activity of the locusts. Although a roosting swarm may remain settled for up to three hours after sunrise, it was found that it is often alert and easily scared away. On some days an attack, even very early in the morning, merely resulted in most of the locusts flying off and only a few thousand or even hundred being knocked down and killed. On other mornings the locusts on being disturbed tried to escape but were only able to jump but not to open their wings, so that large numbers were killed. Those that were not knocked right down into the grass, and those strong enough to come up again, then opened their wings and vibrated them rapidly. A spell of wing fanning enables them to fly afterwards; it presumably acts by warming the body precisely as an aircraft engine is warmed up before the machine takes off, and perhaps also by drying the wings.

The success of beating depends mainly on the time available between the start of operations and the moment when a large proportion of the locusts is able to fly. Cold is apparently the chief factor numbing the locusts. In Rukwa the cold period about dawn only lasts up to three or four hours in the very coldest weather, and sometimes even in winter the locusts were found to be too active at dawn for beating to be effective.

Dew also seems to make the locusts sluggish and unable to fly. It may act partly by keeping the body temperature down and partly by clogging the wings.

The effect of rain seems to vary, probably indicating that temperature is the main factor. During the campaign there was a spell of late showers and two locust officers sent in exactly opposite reports of its effect, one saying that the swarms became more sluggish in the mornings, and the other that they were more active. The writer's one observation agreed with the latter report and suggested that damp without cold increases rather than decreases the morning activity of the locusts and so is unfavourable to beating and other terrestrial control methods.

After the beaters leave a beaten area, a surprising number of locusts crawl out from under the grass. Many of these fly away, but many are injured and cannot fly, most of them dying within a day or two.

In conclusion it may be said that beating is a possible way of destroying swarms of adult Red Locusts, but a very laborious and inefficient one, only possible at all on cold mornings. Under favourable conditions it is probably as effective as baiting, but conditions are more often favourable for baiting than for beating.

(*c*) *Difficulties.*—Apart from the difficulties just mentioned, which cannot be controlled, a very large labour force is needed to destroy even a small swarm. The inefficiency of the method is indeed such that it is seldom possible to destroy a swarm in one day. The locust officers reported that some swarms followed by them became more sluggish after being attacked two or three times, so making further attacks easier. Their biggest swarm of the season was reported as measuring about $1 \times 1 \cdot 5$ kilometres. This was attacked by beating on eight mornings running, eventually with a force of several hundred men, together with about 500 women and 250 children and only a small remnant of the swarm escaped and flew up the escarpment at Mamba Mission. They estimated that the attack on this swarm cost some £250.

The other main difficulty is the same as that already discussed under baiting (p. 362), that of finding the swarms and of getting to the spot in time to destroy them. The difficulty is equally great with beating, the one method needing the transport of a moderate labour force and bulky bait, the other of no bait but of a large labour force.

OTHER CONTROL METHODS.

A. Terrestrial Methods.

This section comprises notes on the values of a number of methods of controlling Red Locusts from the ground, which have not been used by the writer in Rukwa. He has had personal experience of some of them in other areas. Some are recommended, others are not.

1. *Destruction of Eggs.*

In the section on the habits of the Red Locust (p. 334), it has been explained that this species does not lay its eggs in such a manner as to make them easy to find and destroy, except in the case of large swarms. Egg destruction is, therefore, impracticable as a method of control in the outbreak areas. Even under the best conditions it is probably an inefficient method, owing to the difficulty of finding all the egg packets. Some hoppers will usually hatch, whether destruction is by hand digging and collection, by ploughing or by harrowing. In spite of this, eggs have been destroyed systematically in some countries during heavy outbreaks. In the Portuguese colonies especially, hundreds of tons of eggs have been bought from natives for destruction. The method is said to have been effective but costly (Dep. Agric. S. Afr., Inter-State Locust Conf., 1935; Queiroz, 1935, 1937; Cardosa, 1937). The usefulness of egg destruction depends on the economic condition of the country invaded. Where it is possible to organise a campaign by an efficient method on such a scale as to guarantee the entire destruction of all hopper bands, it is better to leave the eggs to hatch and to destroy the locusts entirely in the hopper stage. In backward areas, where such an organisation is not possible, and where any method of locust destruction helps to lessen the pest, egg destruction may be welcomed as an accessory means of control.

2. *Trampling of Hoppers.*

The writer has seen a farmer in Northern Rhodesia destroy a small band of hoppers by making his herd of cattle mill round and round over it. The method has also been used in Kenya (Blunt, 1931). If the cattle are numerous enough and the band sufficiently small, the latter certainly may be destroyed, but more by the scattering than by the killing of the hoppers. If there are no more bands approaching to gather up the scattered hoppers, the latter may become sedentary, revert from phase *gregaria* to *dissocians*, and not invade crops nearby, but if the invasion is more serious the method will be less useful. It is only worth mentioning as a possible auxiliary method for farmers to use on their own land when they are unable to adopt more efficient methods.

3. *Hopper Rollers.*

Machines for rolling over and crushing hopper bands have been invented (*see* Uvarov, 1928), but the writer is not aware that they have been used against the Red Locust. Uvarov points out that they do less killing than scattering of the locusts, the survivors of which may come together again afterwards to reform into bands. The great wariness of the Red Locust, its predilection for long grass country, and its habit of taking shelter in the tough stem bases of the grasses all combine to give these arguments even greater force in the case of this species. These instruments can, therefore, not be recommended at all, either in the outbreak areas or elsewhere, save possibly for occasional use by a farmer who happens to have a heavy roller and no better way of destroying hoppers on his own land.

4. *Hopper Dozers and Catching Machines.*

(*See* Uvarov, 1928.) The objections to these are exactly those which apply against rollers. If anything they apply here with greater force.

5. *Driving.*

The only ground method of locust hopper destruction which can be used inside fields of growing crops is baiting. With the Red Locust the bait has to be thrown in such a way that it sticks to the foliage and it has to be made so wet that burning of the leaves results. With strong-growing crops this damage may be negligible, but with young or delicate plants it may be preferable to drive the hoppers out of the field before destroying them. If conditions are suitable, this may be done quite easily on account of the alertness of the Red Locust. Enough labour to make a continuous line of disturbance visible to the hoppers is needed and it is absolutely essential that the line of drivers advance slowly, otherwise many hoppers will get too tired to advance and will take cover until the line has passed over. An open crop in a clean-weeded field is advantageous as a dense mat of ground vegetation makes driving difficult. It is easier to drive a band along the rows of cultivation than across. Large, dense bands are easier to drive than small, loose ones, owing to their greater activity, and it is only possible during that time of day when the locusts are naturally active. If the head of a band is advancing with the momentum of a large body of hoppers behind it, it is difficult to turn it back and it is best to try to deflect it to right or left. If the momentum in one direction is very strong, it may even be best as a last resort to approach the band from behind and to push it right through the field as quickly as it will go.

Driving hoppers out of a field has to be done carefully or it may defeat its own ends by scattering the band. The hoppers then become sluggish and may stay in the crops until they reach the adult stage, eventually doing more damage than if they had been allowed to pass through undisturbed.

Driving can be recommended, from personal experience, for those limited purposes and conditions for which it is suited. As described above (p. 352) it forms an integral part of the beating method against hoppers.

6. *Metal Barriers.*

The use of portable barriers of metal sheeting placed across the lines of march of hopper bands has been sufficiently described by Uvarov (1928). Though they have been used with effect against other locusts, they are less suitable to the Red Locust, owing to its habit of living largely in long grass, which enables the hoppers to jump over the barriers unless the grass, which makes it difficult to tell the direction of march, is cut first. The sheets and supporting pegs are heavy to transport, a particularly important factor, for communications in Red Locust country are often difficult in the rainy season, and they are also liable to be stolen for a variety of uses. It must be concluded that metal barriers are likely to be less effective with the Red Locust than with most species and that the method cannot compete with more modern practice, paticularly with baiting. Metal barriers could be used for protection of growing crops, especially on compact and highly developed farms. The writer has not had personal experience of their use.

7. *Trenches.*

Trenches have been widely used for trapping moving bands of the Red Locust. They were even used in the Mweru wa Ntipa outbreak area in 1944 by the Belgian locust officer, Mr. H. J. Brédo, against bands resulting from a flying swarm which had laid eggs in the edge of the area. They have been used in the past by the natives of Rukwa during heavy invasions from outside. If made wide and deep enough, and with the forward side sheer or overhanging, and smooth, so as to prevent the hoppers from crawling out again, they can be very effective. The size of trenches depends on the size and age of the band to be caught. The powerful jump of this species (c. 30 cm. in the first stage hopper) must be allowed for. Trenches take time and labour to make and are most useful for protecting the edges of cultivated fields from the inroads of large bands. They are usually more expensive and laborious than baiting or spraying but may be used where these methods are not feasible.

8. *Hand Dusting.*

Red Locust hoppers have in the past been killed in Rhodesia and South Africa by contact with sodium arsenite shaken over them by hand out of 5 lb. tins pierced at one end like a pepper pot. Now that better methods are available, hand dusting is rightly abandoned as dangerous to the operators, expensive in arsenic and relatively ineffective.

9. *New Poisons.*

It will be clear from what has been written in earlier sections that, in most ways the use of arsenicals in spraying, and especially in baiting, is the best method of locust control for general purposes. It will also be clear that the trouble and expense of these methods is largely due to the use of a poison that is very toxic to human beings and to the consequent need of close European supervision, when only the common, unreliable type of African labour is available. For some years past attempts have been made to find new poisons, that would be relatively harmless to human beings, but effective against locusts. All that is necessary to say here is to stress from long field experience the fact that the discovery of such a safe insecticide would revolutionise locust control, especially in the outbreak areas and other remote regions.

10. *Flame Throwers.*

Flame throwers are such spectacular implements that they have captured popular imagination and have been used against locusts in several different countries, especially against adults when young or when numbed by cold.

Although good reports of them have been issued (*e.g.*, Mistikawy, 1930; Ballard, Mistikawi & el Zoheiry, 1932), they have usually been abandoned eventually as dangerous to the operators under field conditions, expensive to run, and not particularly effective (*e.g.*, Oldfield, 1935). Apparently many locusts usually managed to escape the blast of flame. Although attempts to obtain flame throwers for testing under outbreak area conditions were unsuccessful, it is felt that the recent improved models might at least be worth a trial. Against hopper bands they could probably not compete with baiting, but they might perhaps be useful against adults although it would not be possible to use them always owing to the danger of setting light to the dry grass. Their special use in outbreak areas might be against swarms and swarmlets densely settled for the night in green grass at the beginning of the dry season, and against concentrations of phases *solitaria* and *transiens* in patches of tall grass left behind by the grass fires in the latter part of the dry season. Against a general outbreak outside the outbreak areas they are not recommended at all.

11. *Night Burning of Adults.*

In the great uninhabited flood plains of Rukwa North and West an attempt was to have been made in 1945 to destroy by burning the scattered adults and concentrations and particularly the swarms remaining in the northern area. During the day time the Red Locust perceives grass fires at a distance and flies off long before most of the other insects, so the only hope is to catch them at night when torpid with cold. For the method to be successful it is, therefore, necessary for the grass to dry before the nights get too warm. In years of low lake level this might take place, but only trial can prove the success or failure of the scheme. During the dry season in Rukwa a strong, spasmodic, southerly wind blows during the night. The plan was to preserve all the grass from burning till an agreed date (1st September was proposed for 1945) and then to start a line of fires along the southern edge of the flood plains. The fires would soon join and a single wall of fire would sweep rapidly down wind and, perhaps, consume multitudes of locusts. Unfortunately the trial was dropped owing to a change of European staff, but the method is worth giving a fair test.

The Mweru wa Ntipa outbreak area comprises many small, scattered flood plains, in which such controlled burning would not be practicable.

Controlled grass burning over the enormous areas covered by a widespread outbreak is obviously impossible, though doubtless an occasional swarm might lay itself open to destruction by burning, especially in some cold upland. Migrant swarms, however, usually roost in trees, where they are likely to be able to escape from any fire in the grass beneath.

12. *Smudge Fires for Protection of Crops against Flying Swarms.*

It has long been a practice during severe locust outbreaks to prepare fires along the edges of cultivated fields that can be lit and made to give out much smoke when flying swarms appear (Blunt, 1931; Div. Ent. S. Rhod., 1933). The Red Locust is very sensitive to fire and this method is often successful in turning swarms aside but it has limitations, for the duration of locust flights is controlled by weather, and especially by temperature. If a swarm is flying and the temperature drops below the level needed for active flight, the swarm will settle, fire or no fire. Such methods are, therefore, likely to be successful in the heat of the day but not in the evening.

13. *Noise for scaring away Adult Swarms.*

Another old practice is to send people banging tins amongst a swarm that has settled in a crop. If the area is small, the time of day such that the locusts are active, and the number of people large enough, the locusts may move to adjoining ground until they are ready to resume their migration. Locusts, especially the Red Locust, are nervous of moving objects and people moving about certainly disturb them, even without banging tins. It has, in fact, never been proved that the noise of the tins, apart from the movement, has any effect whatever on the locusts. The usual African labourer, however, works much better to a noise than silently and the tins should be used as an encouragement to the labour to keep moving, even if the locusts ignore the noise.

Williams (1933) tried the effect of noises on a swarm of the Desert Locust in a series of careful observations eliminating the effect of movement. He got no reaction at all to an alarm clock, an electric buzzer, the firing of a shot-gun and the beating of tin cans. There was a small reaction to an electric motor horn, while a big disturbance was caused by drawing a triangular file along the edge of a large rip saw.

Pumphrey and Rawdon-Smith (1936, 1936a) found decapitated Migratory Locusts sensitive to pure tones between 500 and 11,000 cycles per second, with greatest sensitivity at about 3,000 cycles per second.

The Sena Sugar Estates of Portuguese East Africa (private communication) reported that the blowing of shrill and powerful steam whistles helped to scare off Red Locust swarms from the cane fields.

It is understood that further work is being done at present on the disturbance of locust swarms by the different noises of aircraft but details are not yet available.

14. *Late Dry Season Baiting in Outbreak Areas.*

It has been pointed out on p. 332, that ph. *solitaria* when numerous in the outbreak areas often concentrates in patches of tall grass left unburnt or only partly burnt at the end of the dry season. These concentrations may remain more or less stationary for up to three months, until they scatter with the first rains. There is good hope of reducing the number of locusts in the outbreak areas below the danger point by attacking such concentrations by bait. The bait should be thrown in the tall grass where the locusts roost by day and night, and on the short grass into which they spread out to feed in the morning. The sedentary nature of these concentrations enables them to be dealt with by quite a small trained staff, who can take their time over the work and do it thoroughly. The main difficulty is water. In Rukwa South the work could be done on foot, but for the great flood plains of Rukwa West and North a battery of stout lorries would be needed to go out over the burnt plains. The suggested party is one European, with forty men and four lorries. Three lorries would transport poison, bait, personnel and water for baiting, which would probably be brackish, and one would fetch firewood, fresh water, food, petrol and oil.

This plan of campaign against the concentrations of solitaries could also be used against such swarms of phase *gregaria* as may remain in the outbreak area till the end of the dry season. The greater mobility of the swarms would be a difficulty, but at this season their movements on the Rukwa plains are often restricted to certain better vegetated areas. It was actually proposed to adopt this plan at Rukwa in 1945 but it was not followed up owing to change of staff.

B. Aerial Methods.

Unfortunately at Abercorn very little information has been available about the progress of the recent experiments in the destruction of Desert Locust swarms with the aid of aircraft. The writer took part in the 1934 Rhodesian experiments in which clouds of sodium arsenite were floated through swarms of Red Locusts

in flight (King, 1934; Internat. Locust Conf., Cairo, 1937, App. 15). He has also seen a demonstration by one of the aircraft used in the South African tests of dusting resting swarms of the same species with sodium arsenite (Naudé, 1934, 1935; Faure & De Villiers, 1937). In addition he has flown over the known outbreak areas and is also familiar with the Red and other locusts from the ground.

The special advantages of attacking the adult stage of this locust and the difficulties of doing so adequately from the ground have already been described (p. 357 *et seq.*). It is, therefore, of great importance to try to perfect an aerial method of attack.

1. *Aerial Scouting in Outbreak Areas.*

In August, 1945, a series of flights was made over the outbreak areas in a small cabin biplane aircraft, a Dragon Rapide. Most of the flights were made at a height of some twelve to twenty metres above the ground and one was struck by the ease with which different species of birds and grasses could be recognised during these low flights. For most of the time attention was directed forwards and sideways, to examine the vegetation zones and drainage systems, but one glance backwards disclosed part of a group of locusts flying about just above the grass tops.

The writer is now almost sure that it would be possible to scout even for solitary adults from the air. The solitaries spend most of the time settled, but during the heat of the day they are easily disturbed into short flights. There is little doubt that they would be flushed at that time by an aircraft flying low overhead. An aircraft being so much faster, the locusts would only be seen by looking downwards and backwards, and an aircraft with good visibility in that direction would be needed, if necessary fitted with a special window. The presumed efficacy of this method should be tested as soon as possible.

There are certain areas in the lakeward parts of the great Rukwa flood plains and the deltas of the rivers, that are more or less inaccessible by foot at some times of year. Aerial scouting would enable these difficult areas to be examined regularly and it would be very useful for reconnaissance of other suspected outbreak areas.

Another advantage of aerial scouting would be the possibility of counting or estimating closely the numbers of locusts in different areas. The advantages of numerical survey both for control and research work are obvious. Various ways of estimating the numbers of locusts from the ground have been suggested and have been used with more or less success with other species (*e.g.*, Golding, 1934a). The solitary phase of the Red Locust lives in grass varying from 0·5 to 5 metres high, in which visibility for man and for locusts is so variable that counts from the ground in different habitats give results that are not comparable and may, therefore, be useless or even definitely misleading. It is very probable that locusts would be flushed with equal ease from short and tall grass by an aircraft flying low overhead at the right time of day so that comparable counts could be made.

At present all scouting in the outbreak areas is done on foot by a resident staff. If further trials of aerial scouting prove effective, it might be possible to abandon all foot scouting during the dry season and do all the routine work from the air.

Solitaria and *transiens* hoppers could certainly not be spotted from the air. It is probable that dense bands of *gregaria* hoppers could be detected when roosting on the tall grass in the evening and morning, but not during the

middle of the day, when they are more scattered and lower down in the grass. During the breeding season aerial scouting could, therefore, only be a subsidiary to ground scouting and only useful during a severe outbreak.

It is obvious that the helicopter will be better for this work than the aeroplane, when it becomes well enough developed to be used in remote tropical areas. Failing this, a scouting aeroplane should be as slow as possible.

2. *Aerial Scouting for Swarms.*

Red Locust swarms, both when flying and when settled, have proved easy to see from the air under a fairly wide range of conditions. The work carried out so far has been during the dry season, when they are dense. As pointed out above (p. 338), swarms of this species become much looser at the beginning of the rains and probably then become less easy to see from above. The African Migratory Locust is probably equally easy to scout for from the air, but the loose swarms of the Desert Locust have proved much more difficult. The experimental work has shown that it is difficult for ground parties to be mobile enough to scout adequately for aircraft doing control work, even where a fair number of roads exists. Since it would often be advisable to attack migrant swarms in the more remote regions, any aerial campaign should be organised to rely on aerial rather than terrestrial scouting.

3. *Aerial Dusting of Swarms.*

The compactness of the swarms of the Red Locust, both in flight and at rest, makes them vulnerable to insecticides from the air. Whether in the outbreak areas or outside, the time to start an aerial campaign is at the end of the rainy season, as the locusts become adults, because this allows several months in which to find out where breeding has taken place and to prepare for the campaign. The first swarms are small and not very active but after a few weeks they amalgamate and start migrating; their usual direction of movement is often known, so that they can be followed. South of the equatorial belt, at any rate, the cold weather follows on fairly soon. This slows down the movements of the swarms again and increases the length of time when they remain sluggish in the mornings and so present sitting targets. When the hot weather comes, they become more active, and consequently more difficult to follow and deal with, and with the first rains they become diffuse and still more difficult both to see and to kill.

Swarms have been attacked both when settled and when flying. From the point of view of the biology of the insect there seems little to choose between either method. A swarm is much more concentrated when settled than when flying so that a smaller area need be covered with insecticide. On the other hand, it is probable that during its life a swarm usually spends more hours of daylight in the air than settled. It is also very possible that a flying locust is more susceptible to insecticides than one settled with its wings folded over its back. Unless further technical difficulties arise, it would seem best to combine the two methods in an aerial campaign, one set of aircraft attacking the swarms when settled in the morning, and another set dealing with them in flight during the heat of the day.

The difficulties so far met in aerial control of the Red Locust are chemical and physical rather than biological. Sodium arsenite was used in the 1934 experiments. In the South African experiments against settled swarms, poison had to be dropped in quantities large enough to be dangerous to man and stock and consequently operations had to be carried out in thinly inhabited areas. The intention in the Rhodesian experiments was to use a dust so fine that it would never sink but would dissipate in the air. In practice it was found that this fine sodium arsenite often caked badly and that lumps of appreciable size, as well as some of the actual clouds of dust, fell to the ground. The quantity dropped was

enough for the local authorities to consider it necessary to flag the poisoned areas near the road to warn farmers and travellers against grazing their beasts in the vicinity.

It is possible that technical improvements may enable arsenical dusts to be dropped from aircraft even in thickly settled country. More hopeful are the trials now in progress with less dangerous insecticides, the results of which will be awaited with interest. There is doubtless much still to be learnt about the best equipment for dropping the dust and the best type of aircraft to use, but the writer is not competent to discuss this. Aerial dusting is unlikely to be able to replace ground methods for the treatment of hopper bands, owing to their being usually much smaller and more numerous than the swarms which arise from them, and often to the necessity of relying on ground scouting.

4. *Aerial baiting.*

Baiting has been done from the air in Russia (Bey-Bienko, 1932; Ivanov, 1934; Lepeshkin, 1934) against locusts and in America (Drake & Decker, 1932) against grasshoppers. It would doubtless also be effective against African locusts and might be used for both hopper bands and adult swarms. If a good technique for dusting can be evolved, and especially if a suitable insecticide more or less harmless to man and stock can be found, baiting would probably be less useful than dusting. The weight of bait to be dropped per unit area is likely to be higher than that of a contact insecticide, an important point in aerial work as it would make baiting more expensive. The same disadvantage would apply in the case of aerial dusting against hoppers. An interval is required for the adults to find and eat the bait, during which they may fly away; no such interval occurs when a contact insecticide is used. A contact insecticide, moreover, can be dropped on to a dense, roosting swarm, while bait must be spread over the much wider area over which the locusts scatter when feeding. The possible usefulness of aerial baiting will depend on the progress in the technique of dusting, for there is no doubt that even an arsenical bait could be scattered from the air in a way harmless to man and stock but fatal to locusts.

Summary and Conclusions.

The best way of preventing locust outbreaks is to control them at their source. After a description of those habits of the Red Locust that have a direct bearing on control, an account is given of some of the results of three years' experience of control of this species in an outbreak area. The methods used in Rukwa are described in detail, and attention is drawn to their relative efficacy, advantages and difficulties. A number of other methods are also referred to and their values discussed. Control methods are considered with special reference to conditions in Rukwa and other outbreak areas, and in relation to large scale campaigns against large outbreaks. Conclusions on the relative values of the various methods are summarised below. These values depend both on the habits of the locusts and on the ecological, economic and social conditions of a country in which a campaign is to be waged. It must not be assumed that conclusions about control methods reached with one locust or in one country necessarily apply to another locust or another country.

Habits.

The Red Locust normally inhabits the moderately humid regions of Africa with a good grass growth. Apart from the eggs, which are laid in the ground, and adult swarms of phase *gregaria,* which largely rest and feed on the foliage of trees, all stages and phases show a preference for more or less tall and dense grass and seldom occur on the ground. The species is more agile, more wary, but less active than some of the other well-known species of locust.

The phase *solitaria* normally lives scattered in open grasslands where it may be slightly gregarious in the hopper stage. When numerous the adults sometimes form sedentary concentrations in tall grass, especially in the latter part of the dry season. Occasionally such concentrations may behave as swarms for a day or two and migrate a few kilometres at the beginning of the rainy season before breaking up. The normal behaviour of both isolated and concentrated adults with the coming of the rains is to scatter widely for breeding.

The phase *transiens* in the outbreak areas lives in the hopper stage in small, loose bands. The adults form swarmlets, which remain mainly on tall grass in the outbreak areas and undertake only short and partial flights. The swarmlets may break up during the course of the dry season and usually do at the onset of the rains, occasionally making a short migration before doing so. After scattering the *transiens* adults adopt *solitaria* habits.

The phase *gregaria* lives in smaller or larger migratory bands and swarms. Except in heavy invasions, the egg packets even of this phase are difficult to find and often scattered. The six hopper stages last about two and a half months, longer than the five stages of most locusts. In incipient outbreaks bands have been found to vary from 1 metre in diameter to about 500 x 200 m. In big outbreaks bands may be up to some kilometres across. A band in a big outbreak very commonly consists of hoppers all of one age; in incipient outbreaks the hoppers in a band are usually of varied ages. The first young adults to mature stay about for a while with the hoppers with which they grew up. This period is naturally longer with incipient bands of mixed age than with the one-age bands of a large outbreak.

Adult swarms of phase *gregaria* roost for the night crowded densely together, at least in the dry season, on trees if present, otherwise in tall grass. In the morning they spread out to feed, partly on trees and partly on ground vegetation, occupying an area several times that of the roosting area. They gradually become more active, with partial, circling flights, which may, as the day gets hot, give way to definite migratory flights, lasting usually until late in the day. Night flights of this species are very rare, settling usually taking place in the afternoon or evening. Further concentration of the locusts takes place after the swarm as a whole has settled, often even after dark. Low temperature and high wind discourage flight. Swarms usually fly in column. During the dry season the flights are low and compact but with the coming of the rains they become diffuse and often high. Swarms in an incipient outbreak have had a maximum size of 7 km. long in flight and 0·5 km. diameter when roosting. Large swarms usually break up into small ones for egg laying, which takes place at night; apart from the tiny egg-laying groups seen by Faure, no concentration for laying seems to take place, but rather the reverse.

Values of different Methods of Control.

The destruction of eggs is inefficient and buying of packets collected by hand is expensive. Egg destruction is only recommended as an auxiliary measure if there is no hope of killing the hoppers by more effective means later.

Trampling of hoppers by cattle is an inefficient method only worthy of occasional use by farmers on their own land against small bands, when better methods are not available.

Rollers, hopper dozers and hopper catchers, never very efficient implements against locusts, are exceptionally unsuitable for the Red Locust and are rightly abandoned.

Sweeping hoppers with hand nets has a limited use in incipient outbreaks, but there are more effective methods.

Metal barriers are less suitable in the case of the Red Locust than in most other species but could be used by farmers to protect the edges of their fields against hopper bands.

Trenches work well against hopper bands if properly made and the soil is suitable; they are most useful for crop protection.

Driving of hoppers is possible if done slowly and carefully. It is sometimes useful for crop protection, and it is an essential part of the beating method. When baiting adults it is sometimes possible to drive part of a swarm into a baited area, but the results are very uncertain.

Beating is an old-fashioned method of killing hoppers, but experience has shown that if properly done it can be just as effective as any other method. It is most efficient against bands which are dense but not too big. Its advantages, relative to other methods, are that less European supervision and a minimum of trained native staff are required, there is no equipment to go wrong, no accessory work outside the actual control measures, no water is needed, and the scouting is very efficient. The disadvantages are that it needs a large labour force, it is hard work, and loses its efficiency on flooded ground, in grass without much cover near the ground and with maturing bands. Against adults beating can also be done, but it is unsatisfactory and only to be recommended as an accessory method in times of great need. Its difficulties are that it can only be used against swarms settled in grass and not in trees and it can only be attempted in cold weather, at night and in the early morning with a very large labour force which it is difficult to get to the resting swarm before it moves on again.

Burning of hopper bands with a ring of fire is occasionally possible in most areas, and has been commonly used in Uganda; if there is enough dry grass, all the hoppers can be killed. Against adults burning by day is useless. Burning by night may occasionally be possible against migrant swarms settled in treeless country in cold weather and a trial is desirable on the larger flood plains of Lake Rukwa directed against adults of all phases.

Flame throwers are in general dangerous, expensive and not very effective in use and they are not recommended for big campaigns. It would be interesting to try them in an outbreak centre at night against swarms and swarmlets densely settled in green grass at the beginning of the dry season and against late dry season concentrations of phases *solitaria* and *transiens*.

Poison dusting by hand against hoppers using sodium arsenite is rightly abandoned as dangerous and not very effective. Dusting with pumps needs a wind to be fully effective and, therefore, is likely to be most useful in the dry season against adults. It would be easier if a less dangerous insecticide than sodium arsenite could be found. With powerful pumps mounted on lorries, dusting might prove useful against late dry season concentrations in the outbreak areas.

Arsenical spraying against hoppers is an effective method that has been widely used in the past but is now generally displaced by baiting. The latter method has been found cheaper in large campaigns in several countries, but this does not necessarily apply elsewhere. The advantages of spraying are that it is effective against hoppers at any stage and is fairly economical with labour. On the other hand, it needs pumps which have to be kept in good repair; it is somewhat dangerous to the operators that time is taken up by precautionary measures for their protection; it also needs close European or other reliable supervision, plenty of water, and it is extravagant in sodium arsenite. Spraying is not used against adults, though power spray pumps could be used against torpid roosting swarms.

Arsenical baiting of hoppers is now the most generally used method of locust control. It is effective against the Red Locust, though the habits and habitats of this species make it less easy to use than against the locusts inhabiting drier countries. It is cheap, although this does not necessarily apply everywhere, requires only a small amount of labour in the actual field operations and no special equipment. Its disadvantages are the difficulties of supplying, mixing and transporting bait material, the danger inherent in the use of poison (less than for spraying) and the time taken up by precautionary measures, the need for close European or other reliable supervision and that for water (less than for spraying), the fact that it is not effective against moulting hoppers and the danger of rain washing the bait off the grass. It is an advantage to the actual field work of the campaign and for long storage, if the bait can be mixed before the campaign, but considerations of cost, availability of base materials and transport may be reasons against factory mixing in some areas. The question must be decided on its own merits separately for each area. Wet mixing must theoretically be more efficient than dry and is undoubtedly better if the bait is mixed in the field. Dry mixing is possible with some base materials and greatly simplifies the operation if done in a bait factory, especially in a cool country. A number of new bases has been tried out; for the Rukwa area finger millet and maize are good but are required for human consumption, and maize bran and the malt and chaff of finger millet are specially recommended. Experiments on the effect of different bait materials under more controlled conditions are needed. Adults also will take bait, but a baiting campaign against adults is very much less effective than against hoppers owing to the mobility of the swarms. The heaviest mortality in the swarms treated was on the second and third days. Bait remains effective against adults for at least several days even though dried up. In a general campaign baiting of adults is only to be recommended as an accessory measure in time of serious need, but it has a limited use against young swarms in the course of formation, especially when the fliers are still mixed with hoppers, and against late dry season concentrations and swarmlets and swarms moving little in outbreak areas.

Hand catching for food by natives may be encouraged as a mild accessory method of destroying adult locusts in swarms. It cannot be considered as an effective part of an organised campaign and should not be used for hoppers.

Smudge fires are often useful for protecting crops against invading swarms of fliers.

Noise.—Certain harsh, shrill noises seem to have some effect, but more research is needed on what noises are heard and reacted to by locusts.

Aerial dusting is unlikely to replace other methods against hoppers, but in the adult stage the Red Locust is an excellent subject for this method, both when flying and especially when roosting. It should be carried out during the dry season and not during the breeding season. Every encouragement should be given to further experiments against both settled and flying locusts.

Aerial baiting should be considered as an alternative to aerial dusting of adults, if technical difficulties in the latter method fail to be overcome. The activity of swarms would make a contact insecticide preferable to a bait, other things being equal.

Aerial scouting has been proved to be effective for swarms and will greatly assist control by aerial methods. It is highly probable that it can be used, even with phase *solitaria,* and its value should be carefully tested in outbreak areas.

New poisons.—The fact that the most effective methods in general use involve the use of arsenicals, which are deadly to man and stock, put certain limitations on campaigns and increase their expense, especially through the need for close

European or other reliable supervision. Every effort should be made to find less dangerous insecticides for both terrestrial and aerial methods, the discovery of which may revolutionise locust control.*

Recommendations for Campaigns.

1. *Widespread Campaigns.*

The best method for general use known at present is arsenical baiting of the hopper stage. In areas where the provision and transport of bait are very expensive, arsenical spraying is a possible alternative, but it is more dangerous to the operators. Both these methods necessitate the presence of European or other thoroughly reliable supervisors of the field work. Where such supervision cannot be obtained, egg destruction, trenches, beating and sometimes burning may be used. Crops may be protected by trenches, metal barriers and driving.

It is to be hoped that it will soon be possible to attack adult swarms by aerial dusting or possibly aerial baiting, using aircraft for scouting also. This will be useful particularly in those remote and undeveloped areas where hopper destruction is most difficult, but it must not be expected that such methods will be cheap for some years to come. Swarms should be attacked as early in the season as possible and very young swarms before migration can be baited from the ground. If aerial attack is not possible, roosting swarms can be attacked with very partial success from the ground by baiting, beating, hand catching and occasionally by burning. With suitable apparatus they could have contact insecticides sprayed in solution or blown in powder form over them, but this is not likely to meet with any startling success. Crops may be protected to some extent from invading swarms by movements of labourers, smudge fires and by certain noises.

2. *Incipient Outbreaks.*

Small outbreaks starting in outbreak areas may be attacked by a variety of methods. The relative suitabilities of these vary with the numbers and quality of the trained staff present, the labour supply, the availability of materials, the severity of the outbreak and the condition of the terrain. The chief aim should be the destruction of hopper bands by beating and baiting and perhaps by spraying. Any swarms escaping a hopper campaign should be baited in the first two or three weeks and as soon as possible attacked by aircraft, if aerial methods become practicable. Failing this, a little can be done in the winter by baiting and by beating combined, if possible, with hand catching by the local inhabitants. Tests with power sprays, powerful dust guns and flame throwers against swarms roosting in the cool weather should be tried as well. Night burning should also be attempted in Rukwa North and Rukwa West. Small swarms remaining on the flood plains in the late dry season could be attacked by baiting, poison dusting and perhaps flame throwers. These last methods would need motor transport, at least on the main Rukwa flood plains.

3. *Control of the Solitary Phase.*

There are two possible means of control of phase *solitaria*, firstly by actual destruction of the adults, secondly by making its habitat unsuitable.

Actual destruction of scattered and congregated adults should be attempted by night burning in Rukwa North and West. Some of the natural increase could be kept down by destroying late dry season concentrations, though it is far from certain that this would be enough to prevent hopper bands from arising in the next generation. These concentrations could be attacked by mobile units equipped

* Since this was written, further experimental work carried out under the aegis of the Anti-Locust Research Centre has indicated that gammexane may be a suitable substitute.

for baiting, dusting and perhaps flame throwing. At this season of the year baiting would be more effective against such concentrations of the solitary phase than against swarms.

Present knowledge of the Red Locust so far indicates three possible ways of making the outbreak areas unsuitable for the species—draining, flooding and the prevention of grass fires. Draining is impracticable in the two known outbreak areas but may be possible in others. Flooding is impossible in Rukwa but may be possible in Mweru wa Ntipa, where an exact survey should be carried out to test its practicability. Prevention of grass fires is possible in both areas but is applicable especially to Rukwa, where it should be given large scale trials in the Rukwa North and Rukwa West flood plains.

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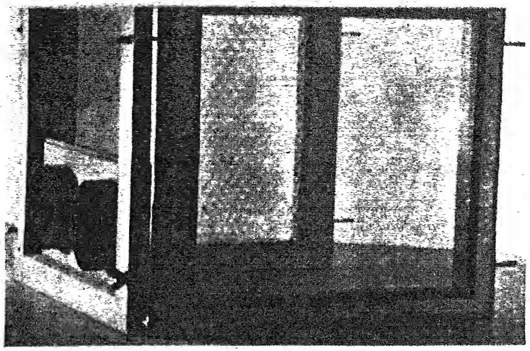
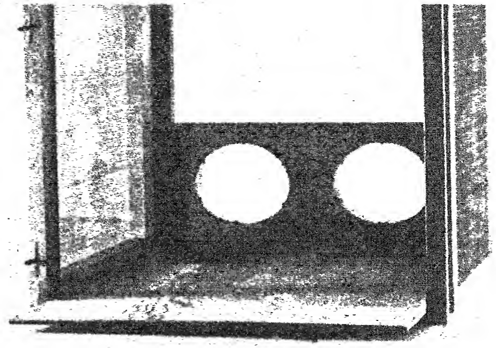


Fig. 1



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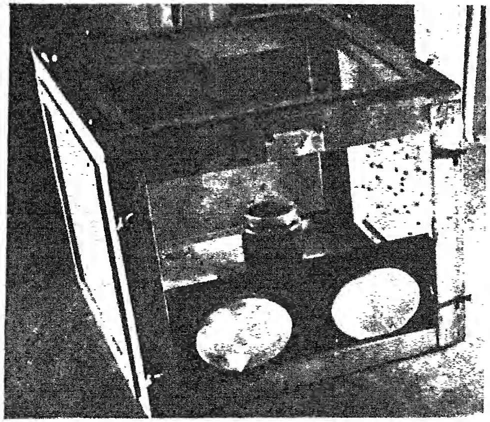

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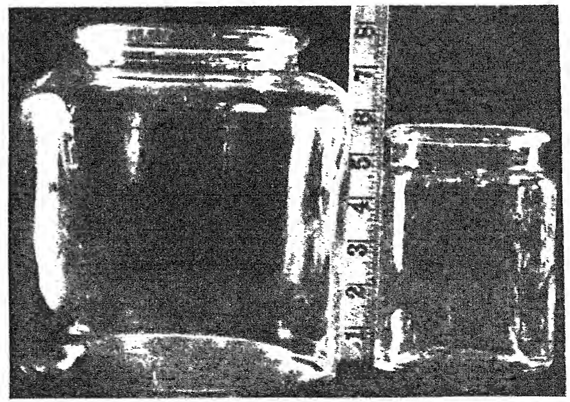
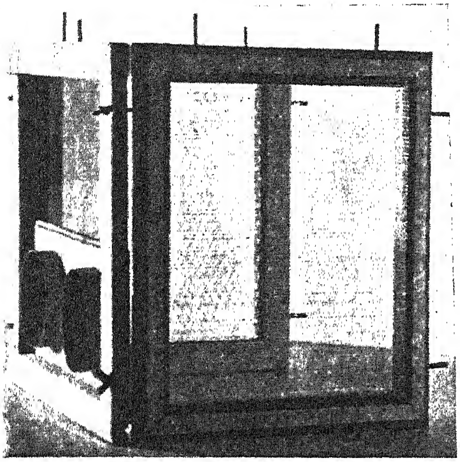


Fig. 4

Fig. 1. Partly assembled cage, showing the front being fixed to the two side panels.
Fig. 2. Partly assembled cage from the back, with bottom nearly in place.
Fig. 3. Completed cage containing flies, water fountain, oviposition jar and sugar (just visible to right of oviposition jar).
Fig. 4. Empty culture jar (left) and empty oviposition jar (right



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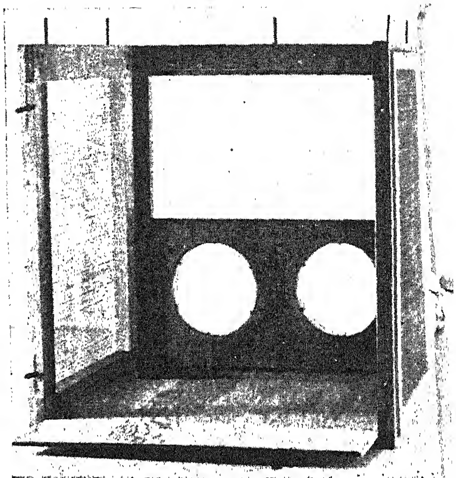

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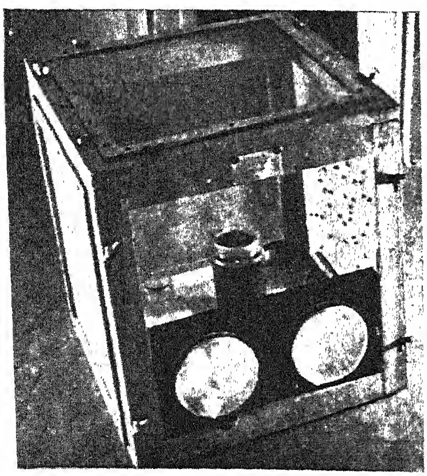

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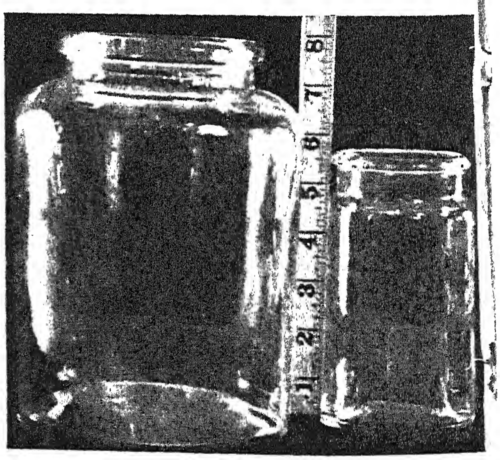

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Fig. 4. Empty culture jar (left) and empty oviposition jar (right).

NOTICE

Please substitute for Plate VII which appeared in "Bulletin of Entomological Research," Volume 37, Part 3, January, 1947.

BREEDING THE HOUSE-FLY (*MUSCA DOMESTICA*, L.) IN THE LABORATORY.

I. Introduction and Technique.

By E. B. Basden.

Department of Scientific and Industrial Research, Pest Infestation Laboratory, Slough.

(Plate VII.)

Introduction.

Since December, 1942, a supply of adult house-flies, averaging approximately 2,500 a day, has been required in this Laboratory for experimental work on fly sprays. The production in quantity of insects suitable for such use is by no means a straightforward matter and a considerable amount of work was undertaken before a satisfactory technique was established.

The present paper gives an account of the equipment and culture methods now in use at this Laboratory. Broadly speaking they are founded on the Peet-Grady fly culture technique (Anon., 1941), but it has been desirable to introduce a number of modifications. It is not claimed that perfection has been achieved but it is possible that a description of the present satisfactory methods may be of use to others.

Breeding Equipment.

A. *Breeding Room.*

The breeding room measures 14 feet × 12 feet × 7 feet 8 inches high. The walls are of brick and are lined with composition board. The room is maintained at $27 \cdot 5 \pm 0 \cdot 5°$ C. and at 60-70 per cent. relative humidity. The heating element, humidifying apparatus, and air circulating fan are in one corner. The only lighting is from five electric bulbs, which are arranged so that adequate illumination is ensured. These lights are on daily from 9 a.m. until 5 p.m. Three racks of slatted shelving, on which the culture jars and oviposition cages stand, are placed away from the walls, thus giving better air circulation and facilitating examination of the cages and jars.

All the normal and experimental breeding work and the emerging and ageing of the flies are carried out in this room. The flies are used elsewhere for the testing of sprays.

B. *Oviposition Cages.*

The oviposition cages have no permanent framework, but are composed of six separate portions (top, bottom, and four sides), which can be assembled by means of dowel screws and wing nuts (Pl. VII, figs. 1, 2 & 3). The external measurements of each cage are 18 inches × 18 inches × 19 inches high. The top, back, and the two side panels are covered with perforated zinc, with the smooth surface to the inside. The top half of the front panel is a sliding plate of glass, and the bottom half is of plywood containing two sleeve holes, each 5 inches in diameter and fitted with a projecting metal collar on which the muslin sleeves are secured by means of rubber bands. The bottom of the cage is of plywood and slides into grooves cut a half inch from the bases of the four side panels.

When in use each oviposition cage is supplied with a water fountain (an inverted jar of water on a layer of absorbent cotton wool), a dish of granulated sugar, and a pad of cotton wool soaked with milk diluted with an equal volume of

water. A shallow layer of dried (skimmed) milk powder in an open dish may be used instead of the " milk pad ". The former does not require the daily renewal necessary for fresh milk but will remain sweet for five or six days. When the adults have begun to oviposit, a jar of freshly mixed larval food, with the milk pad on top, is put into the cage. This " oviposition jar " (Pl. VII, fig. 4) is $5\frac{1}{2}$ inches high × $5\frac{1}{2}$ inches in diameter and is filled with larval food to within a half inch of the top. Placing the milk pad on top of the medium ensures that all eggs are laid in the jar and that the top of the food is kept moist. If the milk pad was separate from the food, some eggs would be laid on the pad and would be wasted. The oviposition jar and milk pad are changed every day, the water fountain and sugar being renewed as often as required. In the Peet-Grady method the floor of the cage is covered with paper, but this has not been found necessary here. When a cage is finished with, it is dismantled and scrubbed thoroughly in clean, hot water, then stored in sections until required again.

C. *Culture Containers.*

The larval cultures are kept in jars measuring approximately 8 inches high × 6 inches in diameter (fig. 4). The jars may be of stoneware or glass, as the length of the developmental period and the size of the insects reared in either type are the same.

Breeding Technique.

To obtain flies for the testing of sprays, clean puparia that do not differ in age by more than two days are put into sleeve cages and the flies emerge in these. Each cage is a muslin sleeve tied over a wire framework, which is 9 inches high and 6 inches in diameter.

Approximately 3,000 puparia are normally required every day (130 puparia in each of 22 sleeve cages). The breeding technique is, therefore, based upon these requirements.

The technique is most conveniently described under four sections, corresponding to each developmental stage of the insect: (A) adult; (B) egg; (C) larval; (D) pupal stage.

A. *Adult Stage.*

Flies not more than one day old are put into the oviposition cages. They are obtained from the normal stock cultures, twelve of which are made up each day. The flies are first lightly etherised, " anaesthetic " ether only being used, and then sexed by examining the genitalia. This can be done very quickly by eye and is more satisfactory than using the relative widths between the eyes. Only the best specimens are selected and 160 of these (80 males, 80 females) are put into each oviposition cage. The adults begin to oviposit three or four days after they have been put into the cage. From this number of flies, which was decided upon after a few trials, sufficient eggs are obtained on each day to produce an average of approximately 4,000 puparia. To maintain an adequate number of puparia a new oviposition cage is set up every week.

The effect of the size of the adults upon egg production has not yet been fully investigated, but it has been found that the smallest flies obtainable from an overpopulated culture oviposited readily and produced normal, vigorous offspring. Similarly the influence of light upon oviposition has not yet been sufficiently studied, but in one experiment flies laid as many eggs in complete darkness as when the lights were on for eight hours out of the twenty-four.

B. *Egg Stage.*

With the Peet-Grady technique a definite volume of eggs is added to freshly mixed food (Anon., 1941). [In the description of the Peet-Grady method it is stated that approximately 500 eggs occupy 0·1 cc. but it has been found here that approximately 700 eggs occupy this volume.] It proved more satisfactory and less time-consuming to allow a certain number of females to oviposit in the oviposition jar, as previously explained, and to let all the eggs hatch. The contents of the jar are then later mixed with an adequate amount of freshly mixed food. (*See* below.)

C. *Larval Stage.*

The size of the resulting adults is determined in the larval stage. The production of vigorous adults with the minimum of variation from the normal size can be accomplished only by ensuring that the larvae have an adequate supply of the right food at the right conditions.

A modified Peet-Grady rearing medium, which in turn is apparently an adaptation of Richardson's original " synthetic " food (Richardson, 1932), is now in use. The composition of the three mixtures is compared in Table I.

TABLE I.

Richardson	Peet-Grady	Basden (Formula No. 6)
3·25 lb. (1474 gm.) wheat bran	3·96 lb. (1800 gm.) coarse wheat bran	4 lb. (1814·5 gm.) middlings
1·75 lb. (794 gm.) alfalfa meal	1·98 lb. (900 gm.) alfalfa meal	2 lb. (907·25 gm.) grass meal
5250 cc. water*	4050 cc. water	6000 cc. tap water
25 cc. " Diamalt "	75 cc. malt extract	60 gm. dry malt extract
56 gm. baker's yeast*	45 gm. compressed yeast	45 gm. dried yeast

In the present formula middlings are used instead of bran as they allow the puparia to be obtained in a cleaner condition. The development of the larvae does not appear to be influenced by the texture of the food and is the same on finely ground bran or middlings as on coarse bran. The middlings completely pass through a 14-mesh sieve. Grass meal is used, as alfalfa meal is unobtainable at the present time. About half of it will easily pass through a 40-mesh sieve, though a little is retained in a 24-mesh sieve. The dry malt extract is more convenient to handle than the liquid, which is usually a 75-80 per cent. solution. It is hygroscopic, but will keep indefinitely in an air-tight tin. The brand of dry malt extract used has the following analysis, which was kindly supplied by the manufacturers:—

Total sugars (maltose, dextrose, dextrin)	85·8 per cent.
Albumenoids	9·3 per cent.
Mineral matter	2·2 per cent.
Acidity as lactic acid	0·6 per cent.
Moisture	2·1 per cent.
	100·0

Diastase 50° Lintner.

* The actual amounts of yeast and water are worked out on the basis that 1 lb. (453·6 gm.) baker's yeast increases the volume of 2000 cc. water to 2420 cc. (actual measurement). 300 cc. of such a suspension were used by Richardson.

Dried, active distiller's yeast has been used throughout for the stock cultures but a cheaper dried, inactive brewer's yeast has been experimented with and has also given excellent results. The quantity of water used ensures that insects of a uniformly large size are obtained and that the food remains moist up to the time the puparia are removed. It will be shown later that puparia are more readily obtained in a cleaner condition from moist than from dry food.

To prepare the food for use, the middlings and grass meal are weighed out, sterilised in a water-jacketted oven, thoroughly mixed, and stored dry in a bin. The suspension of yeast and dry malt extract in warm water is prepared when required and then thoroughly mixed with the appropriate quantity of middlings and grass meal. The food is then ready to receive the contents of the oviposition jar.

The whole of this part of the technique is carried out as follows:—

1. The oviposition jar is placed in the oviposition cage and left there for twenty-four hours.

2. The jar is removed from the cage, fitted with a muslin top, and left for a further twenty-four hours for all the eggs to hatch. The egg stage lasts about twelve hours at 27·5° C.

3. The contents of the oviposition jar, now containing larvae $\frac{1}{2}$ to $1\frac{1}{2}$ days old, are mixed with that quantity of freshly prepared, warm food given in Table I. This amount of food is sufficient for the healthy development of up to 7,000 larvae.

4. The food is immediately transferred to 12 culture jars, care being taken to keep it thoroughly mixed while doing so to ensure even distribution of the larvae. The food should be not more than four inches in depth otherwise some of it will be wasted, as the larvae generally do not penetrate to a greater depth than this in the culture jars.

5. Each jar is then covered with a muslin top, which is kept tight by means of a rubber band to prevent larvae accumulating between the muslin and the top of the jar.

6. The jars are left undisturbed until the puparia are removed six days later. The rearing medium remains damp and should keep free from mould throughout the development of the insects.

D. *Pupal Stage.*

The first few puparia are formed three to four days after the contents of the oviposition jar have been mixed with the main bulk of food. The cultures are then reckoned to be five to six days old, as that time has elapsed since the oviposition jar was originally put into the cage. Two days later all or almost all larvae have pupated. The puparia are then removed and put into the sleeve cages.

There are several methods of collecting the puparia:—

1. By obtaining the fully grown larvae and allowing them to pupate in a clean receptacle. This is most conveniently done by taking advantage of their habit of migrating from the wet food, as follows:—

(*a*) By using shallow containers in which the breeding medium reaches nearly to the top, so that the larvae can wander from the jars and drop into a tray, from which they can be collected or in which they can be left to pupate (Ostrolenk & Welch, 1942). A variation of this method is to surround the food with sawdust in large saucers or pans (Lodge, 1918; Scott, 1919).

(*b*) By placing crumpled cloth or paper on top of the food in the jars and removing the larvae from it at intervals.

(*c*) By spreading the culture medium in a thin layer over wire gauze, illuminating from above, and allowing the larvae to drop into a receptacle (Allen, Dicke & Brooks, 1943; Campbell & Sullivan, 1938; De Bach, 1942; Eagleson, 1940, 1943; Eagleson & Benke, 1938).

(*d*) By washing the food through 16-mesh gauze to separate it from the larvae, so that the larvae are retained on the gauze (De Bach, 1942).

2. By collecting the puparia:—

(*a*) By removing the puparia-laden food, usually about the top inch, and

(i) Leaving it as it is and roughly estimating the number of puparia present (Cox, 1944).

(ii) By picking the puparia out individually.

(iii) By drying the food and separating it from the puparia by means of sifting, rolling, or air current (Anon., 1941; Bickoff, 1943; Hockenyos, 1931; Simanton & Miller, 1938).

(*b*) By allowing the larvae to pupate in crumpled cloth or paper on top of the food in the jars, and removing the puparia from these.

(*c*) By flotation, *i.e.*, by tipping the cultures into water. All puparia more than five hours old will then float and can be decanted off, whereas all the food if wet enough, all larvae, and most puparia less than five hours old will sink.

(*d*) By some mechanical device, such as described by David and Harvey, 1941.

Only methods 2 (*b*) and 2 (*c*) have been employed to a large extent at this Laboratory. Method 2 (*b*) is not now used but it is described here as it may be useful to others. At the time when this method was in use the breeding technique differed in several particulars from that at present employed and pupation was completed over a period of three days and not over two days as now.

After the contents of the oviposition jar had been mixed with the freshly prepared food and this had been put into the culture jars, two pieces of muslin, each about ten inches square, were put on top of the food in each jar. The first-formed puparia were removed from the cultures on the sixth morning after the oviposition jar had originally been placed in the cage. This was done by transferring the larvae and puparia from the cloth to 10-mesh wire gauze placed below a light. The larvae crawled through on to a tray and were immediately returned to the cloth in the jars to give further puparia. The puparia left on the gauze were discarded. Two days later the puparia in the cloth, and now 0 to 2 days old, were gently removed and were retained for use.

The drawback was that not all the puparia in the cultures could be obtained by this method because an appreciable proportion of the larvae pupated in the food. It is possible, therefore, that the sex ratio of the flies used varied more than if all the puparia had been available. Since, as has been shown by Miller and Simanton (1938), the females are more resistant to pyrethrum sprays than are the males, it is important that this possibility of variation in sex ratio should be avoided. (The fact that pupation was spread over a period of more than two days, necessitating the discarding of some puparia, was the result of the technique then in use and is not a criticism of the collecting method.) To obtain all the puparia it would have been necessary to remove also those in the food.

Therefore it was decided to discard this method 2 (*b*) in favour of flotation 2 (*c*). This means that no cloth need be added to the jars and that all larvae pupate in the food. The flotation method has been standardised as follows:—

1. Water at a temperature of $27{\cdot}5° \pm 0{\cdot}5°$ C. is run from a regulated water heater into a bin.

2. The cultures are tipped into this and the whole is stirred gently by hand to break up the food and release the puparia.

3. The mixture is allowed to stand for three or four minutes for the food to settle, then the puparia are carefully skimmed off the surface of the water by means of gauze scoops.

4. The puparia are then transferred to more water, when any remaining food should sink.

5. The puparia are again skimmed off, transferred to absorbent paper on a tray, and dried in a current of air in the breeding room. When dry they are ready to be put into the sleeve cages.

If the food becomes dry or is laden with fine mould growth, which often seems "waterproof", and persistently remains floating, the puparia can be freed of this after the second floating by spraying them gently with water at a temperature of approximately 27·5° C. while they are in a 10- or 14-mesh sieve.

The success of the flotation method depends upon the following three factors:—

1. All or almost all puparia from the cultures are available for use and an adequate number of puparia daily for the sleeve cages is assured.

2. The puparia can always be obtained in a perfectly clean condition.

3. The technique does not affect the emergence or the resistance of the flies. The puparia can be left floating for at least 2½ hours before any adverse effect upon emergence becomes appreciable. In actual practice the puparia are floating for only about ten minutes.

The flotation method is the most certain means of obtaining all the puparia from the culture medium. The only point to be remembered is that most puparia that have been reared at 27·5° C., and that are less than five hours old, will sink in water.

It is extremely important that puparia should never be subjected to such rough treatment as sifting, dropping, or vigorous spraying with water. At one time the occurrence of large numbers of adults that were unable to fly, although completely winged, caused a serious disturbance of the spray testing programme. Experiments conducted in conjunction with Mr. A. A. Green demonstrated that this flightless condition was caused by too vigorous sifting of the puparia in order to separate them from food débris.

The breeding technique may be summarised as follows:—

First day.—The oviposition jar is placed in the cage.

Second day.—(Culture 1 day old). The oviposition jar is removed from the cage.

Third day.—(Culture 2 days old). The contents of the oviposition jar are added to the main bulk of food, mixed, and put into twelve culture jars.

Sixth day.—(Cultures 5 days old). The first puparia are formed.

Ninth day.—(Cultures 8 days old). The puparia are floated off from the food. They are now approximately ½ to 2½ days old.

Seventeenth day.—The flies are ready for use.

Acknowledgements.

The author wishes to express his thanks to Dr. H. H. S. Bovingdon (Hawthorndale Laboratories, Imperial Chemical Industries, Ltd.) for supplying stocks of flies, and to Dr. J. F. Blacklocks (Mrs. E. B. Basden) for criticising the script of this paper, which is published by permission of the Department of Scientific and Industrial Research.

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the

* In the actual publication HARVEY is spelt "HAVREY", which is a printer's error.

COTTON STAINERS (*DYSDERCUS* SPP.) IN THE WEST INDIES.

By E. McC. Callan.

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There has been much confusion in the taxonomy of the species of *Dysdercus* in the Caribbean area, and this contribution is an attempt to straighten out the nomenclature and synonymy for future workers on these important pests, until such time as a complete revision of the Neotropical *Dysdercus* can be attempted.

In the West Indies there appear to be some twelve species of cotton stainers. *Dysdercus fulvoniger* (DeG.), *D. maurus*, Dist., *D. mimus* (Say) and *D. fernaldi*, Ballou, are South American forms, which extend their range to Trinidad and the latter species into Grenada. *D. discolor*, Wlk., is an endemic Lesser Antillean species. *D. andreae* (L.), *D. sanguinarius*, Stål, *D. jamaicensis*, Wlk., *D. fervidus*, Bergr., and *D. fervens*, Wlk., are Greater Antillean species. *D. suturellus* (H.-S.) and *D. mimulus*, Hussey, are North American species, which extend their range into the Greater Antilles. The most important species from the economic point of view are *D. andreae* and *D. discolor*. Ballou (1906), Mumford (1926), Myers (1927), Pearson (1932), Squire (1939) and Callan (1943) among others have studied cotton stainers in the West Indies. Hussey (1929) and Blöte (1931) have made taxonomic revisions of the genus *Dysdercus*.

D. fulvoniger (DeG.).

A South American species. Occurs from Brazil to Colombia, Venezuela and Trinidad.

Blöte (1931) synonymises *D. howardi*, Ballou, with this species. Hussey (1929) regards this species as a synonym of *D. ruficollis* (L.).

D. maurus, Dist.

A South American species. Occurs from Brazil to Colombia, Venezuela and Trinidad.

Blöte (1931) and Pearson (1932) synonymise *D. howardi* var. *minor*, Ballou, with this species.

D. mimus (Say).

A widely distributed South American species extending into Central and North America. Ranges from Brazil through the Guianas to Venezuela and Trinidad, and from Bolivia to Peru, Ecuador and Colombia, through Central America to Mexico and Texas, Arizona and California, U.S.A.

D. fernaldi, Ballou

A South American species. Occurs from Brazil through Bolivia and Peru to Colombia, Venezuela, Trinidad and Grenada.

D. discolor, Wlk.

An endemic Lesser Antillean species. Occurs through the Lesser Antilles from Montserrat to Grenada.

Hussey (1929) regards *D. delauneyi*, Leth., as a synonym of this species.

D. andreae (L.).

A Greater Antillean species. Ranges from Florida, U.S.A. through the Greater Antilles and the Lesser Antilles as far south as Guadeloupe.

D. sanguinarius, Stål

A Greater Antillean species. Occurs in Cuba, Jamaica, Haiti and Puerto Rico.

Hussey (1929) regards *D. jamaicensis,* Wlk., and *D. neglectus,* Uhl., as synonyms of this species.

D. jamaicensis, Wlk.

A Greater Antillean species, superficially very similar to *D. sanguinarius,* Stål Occurs in Cuba, Jamaica and Haiti.

Hussey (1929) synonymises this species with *D. sanguinarius.* Pearson (*in litt.,* 1943) maintains that *D jamaicensis* is a valid species.

D. fervidus, Bergr.

A Greater Antillean species. Recorded from Cuba.

D. fervens, Wlk.

A Greater Antillean species. Recorded from Haiti.

D. suturellus (H.-S.).

A North American species extending into the Greater Antilles. Occurs in southern U.S.A. and Cuba, and has also been recorded from Jamaica and Puerto Rico.

D. mimulus, Hussey

A widely distributed North and Central American species extending into the Greater Antilles. Ranges from Texas, Arizona and California, U.S.A., through Mexico and Central America to Panama and from Florida, U.S.A. through Cuba, Jamaica and Haiti.

Hussey (1929) synonymises *D. mimus* (Say) in part with this species.

Geographical Catalogue of West Indian Cotton Stainers.

Cuba.
- *D. andreae* (L.).
- *D. fervidus,* Bergr.
- *D. jamaicensis,* Wlk.
- *D. mimulus,* Hussey
- *D. sanguinarius,* Stål
- *D. suturellus* (H.-S.).

Jamaica.
- *D. andreae* (L.).
- *D. jamaicensis,* Wlk.
- *D. mimulus,* Hussey
- *D. sanguinarius,* Stål
- *D. suturellus* (H.-S.).

Haiti.
- *D. andreae* (L.).
- *D. fervens,* Wlk.
- *D. jamaicensis,* Wlk.
- *D. mimulus,* Hussey
- *D. sanguinarius,* Stål

Puerto Rico.
- *D. andreae* (L.).
- *D. sanguinarius,* Stål
- *D. suturellus* (H.-S.).

St. Kitts.
- *D. andreae* (L.).

Antigua.
- *D. andreae* (L.).

Montserrat.
- *D. andreae* (L.).
- *D. discolor,* Wlk.

Guadeloupe.
- *D. andreae* (L.).
- *D. discolor,* Wlk.

Dominica.
- *D. discolor,* Wlk.

Martinique.
D. discolor, Wlk.

St. Lucia.
D. discolor, Wlk.

St. Vincent.
D. discolor, Wlk.

Barbados.
D. discolor, Wlk.

Grenada.
D. discolor, Wlk.
D. fernaldi, Ballou

Trinidad.
D. fulvoniger (DeG.)
D. maurus, Dist.
D. mimus (Say)
D. fernaldi, Ballou

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FACTORS INFLUENCING THE INTERACTION OF INSECTICIDAL MISTS AND FLYING INSECTS.

Part IV. Some Experiments with Adjuvants.

By W. A. L. David and P. Bracey.

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Introduction.

There has always been a considerable incentive to discover ways of reducing the quantity of pyrethrins incorporated in domestic "fly-sprays" owing to the high price of the extracts and it has been shown that the addition of certain substances, not in themselves insecticidal, leads to a considerable increase in the efficiency of the sprays. Such materials have been variously described as activators, adjuvants or synergists. The best known examples are probably isobutyl undecylenamide (IN 930) (Weed 1938) and sesame oil (Eagleson 1942) which very appreciably enhance the efficiency of pyrethrum sprays employed in the control of house-flies (*Musca domestica*, L.).

At the time when the experiments described in this paper were initiated, there was a world shortage of pyrethrum extract and evidence was required that adjuvants were also effective in anti-mosquito sprays. It has since been shown by McGovran and Fales (1944) and David and Bracey (1944) that the efficiency of pyrethrum sprays tested against *Aëdes aegypti*, L., is increased by the addition of both IN 930 and sesame oil.

Both the adjuvants referred to above are relatively non-volatile substances and their inclusion in the spray formulae decreases the volatility of the spray droplets and so leads to an increase in the persistence and particle size of the mists. This effect and its implications have been considered in two earlier papers (David 1946, 1946*a*). The conclusions reached were, firstly that under circumstances where the addition of an adjuvant to the spray increased the particle size of the mist, a large part of the resulting increase in kill observed was dependent upon this effect; secondly, that in so far as the increased kill was dependent upon the increment in particle size it could be obtained by adding such non-volatile substances as heavy lubricating oil to the spray; thirdly that, in addition to the increment in the percentage kill attributable to this effect on the particle size, true adjuvants further enhanced the efficiency of the spray in a manner which remained unexplained. Thus, under circumstances where there was no effect on the particle size distribution, the latter unexplained effect was still apparent. The present paper describes further experiments on adjuvants without, however, explaining their final mode of action.

Methods.

A full description of the apparatus and the general methods employed has been given in a previous paper (David 1946). Essentially the apparatus consisted of a spray chamber maintained at 28° C. and brought to 70 per cent. relative humidity. The test insects (*Aëdes aegypti*) were exposed to the spray mist in cages with gauze ends or alternatively, when the impaction procedure of applying the spray was used, on a disc of mosquito netting through which known quantities of the spray treated atmosphere were drawn at known wind speeds. The latter procedure and the apparatus employed have already been described (David & Bracey 1946).

Assessment of the Results.

Batches of insects ranging from one to four days old were used for the tests and about 100 individuals were employed in each test. Eighteen to twenty-four hours after the exposure the separate percentage kills of males and females were determined and the average of the figures was reported as the final percentage kill. Any insect showing slight movements when examined was counted as alive. In certain cases the results of the individual tests were converted to angles (Bliss, 1938) on which an analysis of variance was carried out.

The Decrease in the Rate of Knockdown in the Presence of Adjuvants.

In all experiments it was consistently observed that the addition of an adjuvant to a pyrethrum spray decreased the rate at which *Aëdes aegypti* was paralysed (knocked down). This effect is illustrated in fig. 1 in which the knockdown rate of 0·05 per cent. w/v pyrethrins is compared with that of 0·05 per cent. w/v pyrethrins containing an activator. The curve for pyrethrins plus activator represents the effect of adding either 5 per cent. v/v sesame oil or 1·5 per cent. v/v of IN 930. The test was carried out under the standard conditions, 0·7 c.c. of spray being injected into the chamber.

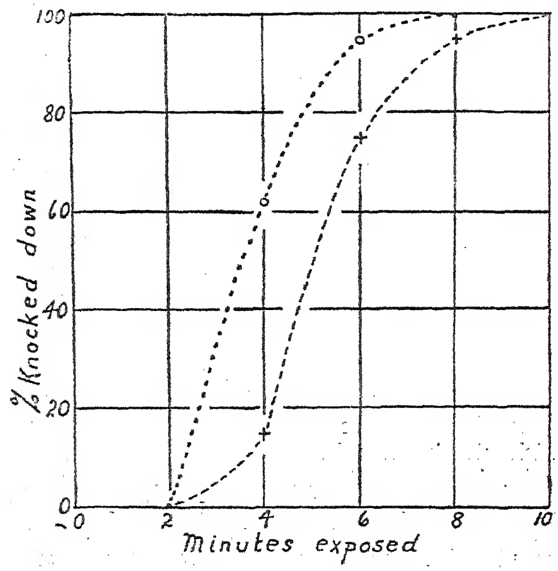

Fig. 1.—The delay in the occurrence of knockdown following the addition of an adjuvant to a pyrethrum spray. Pyrethrins 0·05% w/v = . . . o . . . Pyrethrins plus 1·5% IN 930 or 5·00% v/v sesame oil = – – – × – – –. The lines represent the average of four determinations under standard testing conditions.

The observation just described suggested three possibilities. Firstly, that the slower rate of knockdown with the activated spray was due to the fact that the pyrethrins reached the insect in droplets of solution which were both more dilute and more viscous than would otherwise have occurred, and that from such droplets the pyrethrins penetrated more slowly; secondly, that in the pyrethrum and adjuvant spray the insects came into active flight on the average later than they did in the pyrethrum spray, which would account for the delay in knockdown. Thirdly, that if suggestion two was incorrect then the possibility remained that the spray containing adjuvant acted more slowly than the plain pyrethrum spray and that since the insects flew for a longer period through the mist they would

accumulate more insecticide, which would ultimately penetrate and account for the enhanced kill. Observations relevant to the first and third suggestions are given below.

(*a*) Dilution of the pyrethrins as an explanation of the delay in the occurrence of knockdown observed in the presence of adjuvants.

Haller & others (1942) showed that the sesamin in sesame oil was responsible for the activating effect in pyrethrum sprays applied to house-flies and, when a supply of pure sesamin became available (Mr. B. A. Ellis kindly undertook the preparation), it was tested in anti-mosquito sprays and found to be effective. It also led to a delay in the occurrence of knockdown when added to a pyrethrum spray at the rate of 0·2 per cent. w/v of pure sesamin (fig. 2).

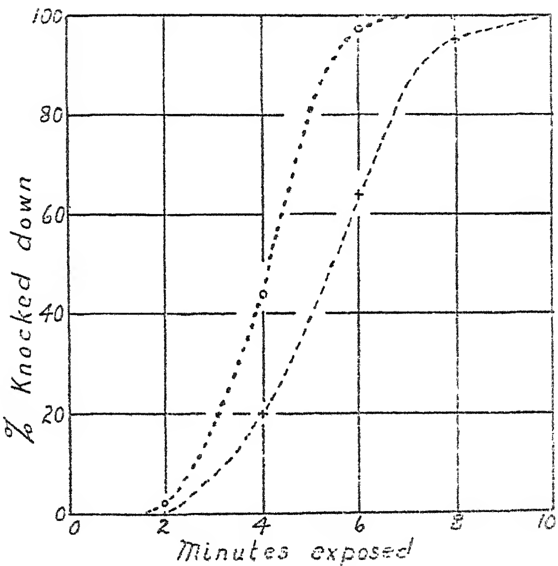

FIG. 2.—The delay in the occurrence of knockdown following the addition of pure sesamin to a pyrethrum spray. Pyrethrins 0·05% w/v = . . . o . . . Pyrethrins plus 0·20% w/v sesamin = – – – x – – –. The lines represent the average of four determinations under standard testing conditions.

Since the decrease in the rate of knockdown was as great as with 0·2 per cent. w/v sesamin as that observed with 5 per cent. sesame oil it seems improbable that the delay is to be attributed to alterations in the concentration or viscosity of the spray droplets.

(*b*) Prolongation of the period of flight as an explanation of the enhanced kill produced by adjuvants.

If it could be shown that activation took place under circumstances where there was no prolongation of the period of flight through the spray mist, the suggested mode of action of adjuvants made in point three above would be excluded. This was achieved by applying the spray by the impaction method in which the spray treated atmosphere was drawn past chloroformed insects (Table I). It can be seen that under these circumstances lubricating oil leads to an increment in the percentage kill (due to its effect on the particle size of the mist) but that the adjuvants enhance the effectiveness of the sprays still further. It is, therefore, apparent that adjuvant action is independent of a prolongation of the period of flight as postulated above.

TABLE I.

Application of various Spray Mists by the Impaction Method.

Insecticide	Average % kill in 24 hours	Average angle ± 2·1
Pyrethrins 0·10% w/v	97	81
Pyrethrins 0·05% w/v	53	47
Pyrethrins 0·05% w/v ... Sesame oil 5·00% v/v ...	100	90
Pyrethrins 0·05% w/v ... IN 930 1·50% v/v ...	100	90
Pyrethrins 0·05% w/v ... Lubricating oil 5·0% v/v	81	64

Equal volumes of the treated atmosphere were drawn past the chloroformed insects at about 2·8 m.p.h. IN 930 represents iso-butyl undecylenamide. Each average is based on two tests with about 100 *Aëdes aegypti*.

The Adjuvant and the Pyrethrum Spray applied separately.

In order to dissociate adjuvant action entirely from any physical effect on the spray mist dispersion, the sprays of adjuvants and pyrethrins were applied separately. A batch of insects was lightly chloroformed and treated with the adjuvant spray by the impaction method. After an interval of fifteen minutes the pyrethrum spray was applied. In order to obtain the maximum effect with the pure sesamin spray it was necessary to add about 2 per cent. v/v of lubricating oil in order to increase the particle size and so the impactibility of the mist droplets. From the results given in Table II it can be seen that adjuvant action was still apparent under these circumstances, with sesame oil, sesamin and IN 930 but

TABLE II.

Sprays containing Adjuvants and Pyrethrins applied separately by the Impaction Method.

Spray applied first	Average % kill in 24 hours	Average angle ± 1·4
Odourless kerosene	24	29·5
Odourless kerosene with 2% v/v lubricating oil	29	32·0
Odourless kerosene/acetone 90/10 with 0·2% w/v Sesamin ...	48	44·0
Odourless kerosene/acetone 90/10 with 2% v/v lubricating oil and 0·2% w/v Sesamin ...	79	62·5
Odourless kerosene with 2·0% w/v IN 930	66	54·0

The composition of the adjuvant spray applied first is given in column one, the second spray was 0·05% pyrethrins in odourless kerosene. The average figures are based on two determinations using about 100 insects for each test.

not with lubricating oil. It must be concluded, therefore, that the adjuvants exert their action independently of any effect on either the particle size of the spray mist or the behaviour of the insects. In other words they increase the effectiveness of the pyrethrins and not the quantity of insecticide accumulated.

Adjuvant Action with DDT.

An investigation was carried out in order to ascertain whether adjuvant action could be demonstrated with 2, 2 bis (parachlor phenyl) 1, 1, 1 trichlorethane (DDT). Although both the standard testing procedure with flying insects and the impaction method were employed, no evidence of adjuvant action was obtained. The most critical experiment was probably one in which the adjuvant and the DDT sprays were applied separately. Under these circumstances adjuvant action is apparent with pyrethrins but could not be demonstrated with DDT as Table III shows.

TABLE III.

Sprays containing Adjuvant and DDT applied separately by the Impaction Procedure.

Spray first applied	Average % kill in 24 hours	Average angle ± 1·7
Odourless kerosene	47	43·0
Lubricating oil 2% v/v in odourless kerosene	40	39·0
Isobutyl undecylenamide 2% v/v in odourless kerosene	47	43·5
Sesamin 0·20% w/v + lubricating oil 2·0% v/v in odourless kerosene	38	37·5

The composition of the adjuvant spray applied first is given in column one. The second spray applied was always 0·3% w/v DDT *in odourless kerosene. Interval* between applications 15 min. approximately. Wind speed through impactor 2·4 m.p.h. The average figures are based on two determinations employing about 100 insects for each.

Summary and Conclusions.

The yellow fever mosquito, *Aëdes aegypti*, has been employed in experiments on the mode of action of adjuvants. With this insect under the test conditions employed, a decrease in the rate of knockdown was observed as a result of adding sesamin, sesame oil or IN 930 to a pyrethrum spray. It was shown that the increment of kill produced by activators was not attributable to any effect on either the particle size of the mist or the behaviour of the insect which led to an increase in the dose accumulated during the test exposure. No activating effect was apparent with DDT. The final mode of action remains unexplained.

Acknowledgements.

We wish to thank Professor P. A. Buxton, F.R.S., and Dr. V. B. Wigglesworth, F.R.S., for their interest in this work, which has been carried out under a grant from the Medical Research Council.

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INITIAL EXPERIMENTS IN THE USE OF DDT AGAINST MOSQUITOS IN BRITISH GUIANA.

By C. B. SYMES and A. B. HADAWAY.
(*Colonial Insecticide Research.*)

(Pl. VIII.)

CONTENTS.

Introduction.

The investigations to which these records refer were conducted in co-operation with Dr. Giglioli, Malariologist, British Guiana, and his staff, and with Professor V. La Mer and Messrs. Hodges and Rowell, of Columbia University, New York, who had come to British Guiana to test the Hochberg-La Mer generator under tropical conditions.

The initial plans had to be modified considerably because of delays in the arrival of equipment and materials, and had to be confined to small trials of "residual" DDT in three areas, and to one test only of the generator. Most of the residual applications were made with a hand pressure sprayer loaned to us by Dr. G. Bevier of the Rockefeller Yellow Fever Service. The single generator test had to be conducted with a small trial machine because the larger model had developed serious faults. The observations consequently must be regarded as very incomplete.

British Guiana has a population of about 340,000, just over a third of whom are of African descent, but with a large number of East Indians brought in over a long period for labour on the sugar plantations and considerable Portuguese and Chinese communities. Aboriginal Indians are few in number and live almost entirely in the southernmost parts of the country, near the Brazilian and Venezuelan borders.

Climate is warm, equable and damp over the northern coastal areas. In Georgetown, the capital, rainfall averages about 94 inches a year, mean shade temperatures vary between 79° and 84° F. and mean humidities between 63 and 85 per cent. at 1 p.m. and between 80 and 95 per cent. at 7 a.m.

TABLE I.

Georgetown—Meteorological Records.

Mean monthly figures 1935–1944 inclusive.

—	Temperature °F.			Relative Humidity %			Rainfall in inches	Evaporation in inches
	Mean shade	Mean max.	Mean min.	7 a.m.	1 p.m.	6 p.m.		
January	79·8	84·2	75·5	88·2	75·7	81·6	8·74	4·54
February	79·8	84·3	75·7	85·6	72·2	78·3	4·86	4·79
March	80·5	84·8	76·2	84·5	72·0	79·6	5·37	5·64
April	80·9	85·2	76·7	86·1	73·6	80·5	6·74	5·21
May	80·9	85·2	76·7	89·5	76·9	82·7	10·90	4·69
June	80·2	84·7	75·7	92·7	78·9	83·7	14·30	3·60
July	80·4	85·4	75·4	93·7	76·1	81·7	11·39	4·37
August	81·3	86·6	75·9	91·9	74·0	79·9	7·20	5·18
September	82·4	87·7	77·0	90·4	68·5	79·5	3·22	5·74
October	82·5	88·2	76·9	88·4	68·9	80·5	3·87	5·65
November	81·9	86·9	76·8	88·0	70·6	80·9	4·51	4·74
December	80·6	85·4	75·8	90·8	75·9	82·4	13·64	3·86
					Total ...	...	94·74	58·01

A strong N.E. breeze blows almost constantly, producing a high rate of evaporation.

More than five-sixths of the population live in the very narrow coast belt, much of which is at or below sea-level. Large numbers, mostly of the East Indians, work on sugar estates, but there is a growing tendency towards independent production of rice and other crops and small-scale farming.

The middle and eastern coastal areas have been devoted to sugar production for many years. This has made necessary the construction of long sea walls, and many pumping stations to keep out sea water as well as the construction of miles of drainage canals. Fresh water from extensive flooded collecting areas in the immediate hinterland is introduced by means of more miles of canals and this is used for maintaining the fresh water table generally, flood-fallowing of sugar-cane fields every few years, rice production, and for domestic purposes. At all times there are square miles of areas flooded with fresh or, near the sea, with brackish water. These, together with the extensive canals and drains, provide adequate facilities for a big mosquito production.

Malaria is very prevalent except apparently in the far eastern portion of the coast belt where there is no sea wall, an excess of sea or brackish water unsuitable for Anopheline vectors, and open windswept front lands. Many of the people here live in areas flooded at each high tide by sea water. Over the great part of the populated coast belt, however, malaria is hyperendemic.

Filariasis is also very common. Elephantiasis is unusually obvious in certain suburbs of Georgetown.

Anopheles darlingi, Root, is the most important malaria vector in British Guiana, and is present in large numbers throughout the year, increasing during the wetter periods. Breeding is widespread in the many miles of canals, drains, and other surface waters. Adults converge on the dwelling places, and readily enter houses. This species is " domestic " in habits, large numbers of females being found in houses at all times of the day and night. Common resting places are the under surfaces of furniture (shelves, beds, tables), walls, and hanging clothing. Large numbers rest on the undersides of roofs, or on ceilings if these are present.

A. aquasalis, Curry (= *tarsimaculatus,* auct.) and *A. albitarsis,* Arrib., are not important as vectors in British Guiana according to Dr. Giglioli. In coastal areas they feed primarily on animals (cattle and donkeys). These two species are more seasonal than *A. darlingi.* Specimens were captured in a Shannon " Dawn " Trap and in cattle stalls at the Veterinary Stock Farm, but they were recorded only rarely in houses.

Culex fatigans, Wied., is very common. It was found in extremely large numbers in Lodge Village, a suburb of Georgetown, and it is probably responsible for most of the filariasis there.

Residual Applications of DDT in Houses.

The trials were conducted on Lusignan and Mon Repos sugar plantations situated at about 11 miles and 8 miles, respectively, east of Georgetown: and in the La Grange rice growing area on the west bank of the Demarara river.

The procedure adopted consisted of:—

(i) preliminary mosquito catches in representative rooms;
(ii) survey of population of the experimental houses, including controls, and of their living conditions;
(iii) examination of children by Dr. Giglioli for malaria incidence;
(iv) application of insecticide;
(v) mosquito catches continued as long as was useful;
(vi) subsequent malaria surveys.

Mosquito captures in rooms were made both by the use of ordinary hand capture tubes, and by " flitting " and collecting immobilised mosquitos on white sheets. " Flitting " consisted of filling the room quickly and thoroughly from the

ceiling downwards with a mist of atomised pyrethrins 0·1 per cent. in kerosene. Two large flit-guns were used. A comparison of results obtained by these methods is given in Table II.

TABLE II.

Comparison of the numbers of adults collected at Lusignan and Mon Repos.

No. of rooms	Hand captures		"Flit" captures	
	Total mosquitos	Mean	Total mosquitos	Mean
Untreated - 32 ...	980	30·6	3276	102·4
Treated - 28 ...	11	0·4	79	2·8

The "flitting" captures were made in the same rooms on the same mornings, later than those collected by hand.

Though the "flit" gave a much better picture of mosquito population than the hand captures, both were employed in all experiments.

All daily routine captures were made between 6 a.m. and 12 a.m. commencing as soon after daybreak as possible. In the majority of quarters on the estates, bed and living rooms are one, but this does not apply to La Grange and to Lodge Village where most houses have at least two rooms.

A census of human populations in experimental areas and a survey of their living conditions appear to be necessary if we are to understand all essential factors likely to influence initial mosquito densities and the effects of insecticides on them. Occupants, together with their soiled clothing, are attractants to mosquitos and, other things being equal, the size or odour of the attractant should show some relationship to the number of mosquitos attracted to the room. Haddow (1942) has shown this to be so in Kisumu; and since *A. darlingi* is perhaps more "domesticated" than *A. gambiae*, Giles, it may almost certainly be assumed that it reacts in similar fashion.

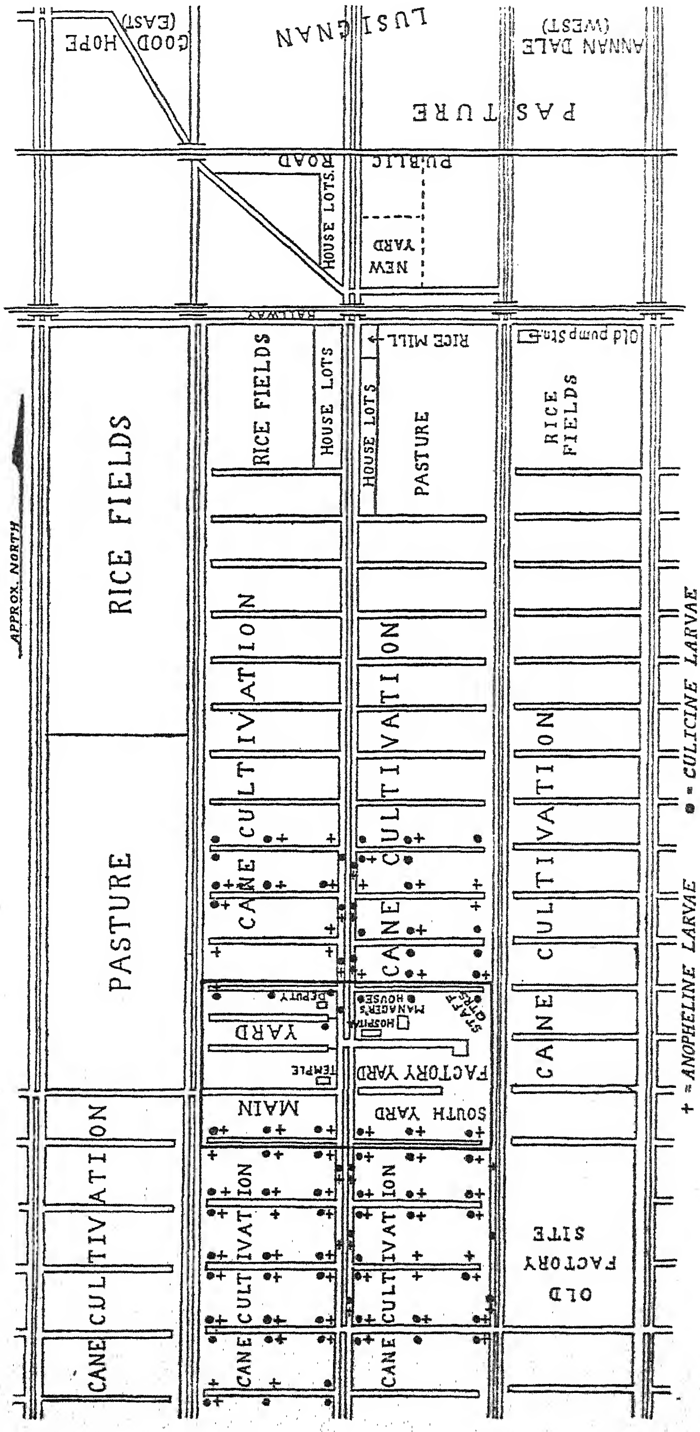
Rooms with dark walls and roofs might be expected to harbour more mosquitos during daylight hours than those with light interiors. Mud walls retain more of the solution applied than do hard wood or glazed-papered walls but they absorb it, and deep absorption may result in serious loss of effect. Thatched roofs (without ceilings) offer more facilities for mosquito harbourage than wood or iron, and are more absorbent. Much furniture in a room adds to the task of applying the insecticide yet if it is not treated much resting surface remains on which mosquitos may escape contact.

These and other factors almost certainly influence results. The data are not yet sufficient to indicate the degree of such influence and they have not, therefore, been included in these notes but observations during later stages of the experimental period, when the effects of applications are lessening, may well be useful.

Lusignan.

Plan I shows the surroundings and layout of this plantation. It is typical of most sugar estates, with a middle road bordered by two canals running the whole length, numerous cross canals branching from them, and long side canals. All cane is transported from fields to factory in punts drawn by mules. The areas between the cross canals are all fields of which some are always under flood fallow. After about four years of production, the fields are flooded to a depth of a foot or so over a period of 6 to 9 months, during which time the soil regains its fertility and the fields can then be replanted with sugar. During flood fallow there is a

heavy growth of vegetation on the fields and, for a certain period at least, a prolific production of mosquitos.

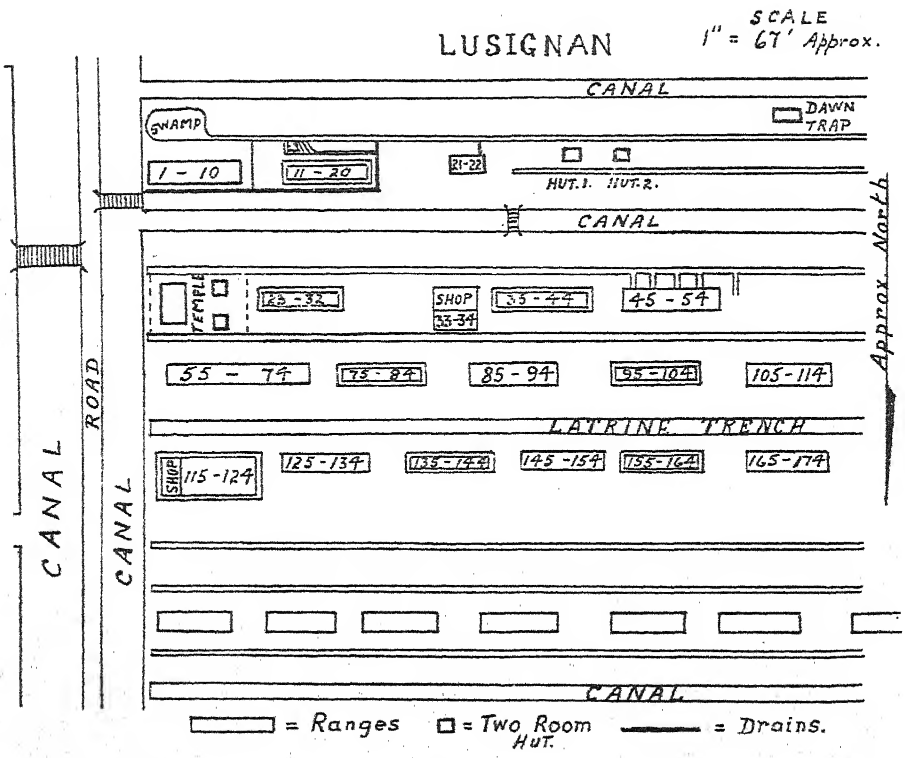


Plan I.

Rice cultivation is of the wet type, with prolonged flooding, and this is a source of abundant mosquitos. The pasture areas shown are mostly old cane fields that have lost their fertility for sugar cane and are given over to grass. They retain the remains of their cross canals, and have usually, therefore, considerable areas of breeding grounds.

It may be appreciated then that with miles of small canals and ditches many of which are very nearly stagnant—though the levels rise and fall gently with those of the main canals—acres of flooded cane fields, rice fields and pastures, mosquito output is appreciable.

Plan II shows the layout of part of the Yards including the labour quarters or ranges. A " range " is a block of usually 10 rooms (each about 10 feet by 10 feet) with a verandah or gallery running down one side. It measures about 100 feet long by 21 feet wide, and about 20 feet high at the ridge. Most of the old ranges each consist of 10 rooms but new labour quarters of two-roomed cottages are being provided. The system of cross canals is maintained in the Yard area and there are many subsidiary drains and special latrine trenches (Pl. VIII, figs. 1, 5).



Plan II.

Most of the ranges are raised a foot or two above ground level but a few are higher with space underneath for goats and a variety of articles, mostly rubbish.

Ranges selected for experimental purposes are shown numbered. Those with double outline were sprayed; the others were used as controls. The positions of the two experimental huts (Pl. VIII, fig. 2) and a Shannon " Dawn " mosquito trap are also shown.

Population in our experimental ranges totalled 198 adults and 153 children.

Fig. 1.

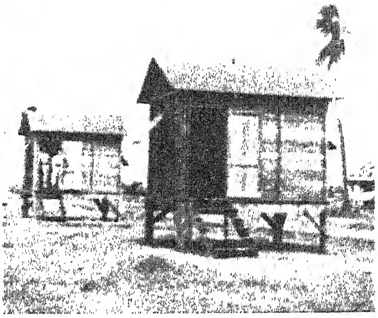


Fig. 2.

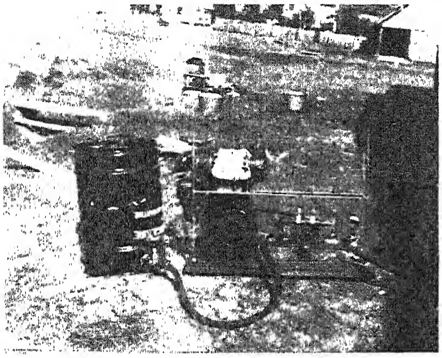


Fig. 3.

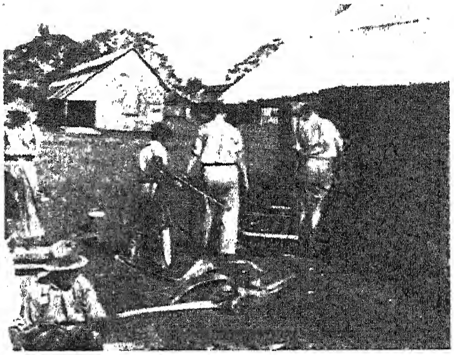


Fig. 4.

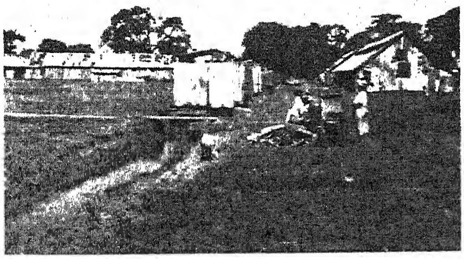


Fig. 5.

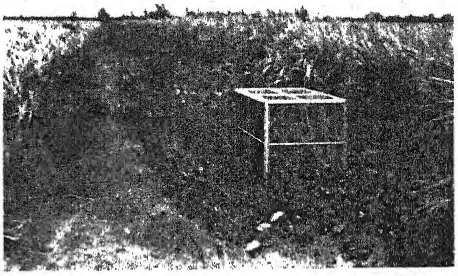


Fig. 6.

Fig. 1. Canal at Lusignan. Labour Ranges on left and right.

Fig. 2. The two huts specially constructed for night observation at Lusignan.

Fig. 3. Small motor powered sprayer with insecticide tank. Used at Mon Repos.

Fig. 4. The small motor powered sprayer being carried at Mon Repos.

Fig. 5. Mon Repos. A latrine trench.

Fig. 6. Field "emergence" cage, in a canal.

Malaria is hyperendemic. In his survey of March, 1945, Dr. Giglioli recorded as follows:—

Children examined	... ...	150
No. with enlarged spleens	... ...	108 = 72 per cent.
,, ,, blood parasites	... ...	83 = 55·3 per cent.
,, ,, gametocytes	... ...	18 = 12 per cent.
,, ,, *Plasmodium vivax*	... ...	30
,, ,, *P. falciparum*	... ...	24
,, ,, undifferentiated rings	... ...	27
,, ,, crescents	... ...	15 = 10 per cent.

Temperatures and humidities were recorded in one room of a range in the experimental area between 10th February and 12th April. The maximum temperature varied between 90 and 77° F. with a mean of 86·4° F., whilst minimum temperatures ranged from 78 to 73·5° F. with a mean of 76·1° F. Mean relative humidities were 84·4, 72·8 and 81·8 at 6 a.m., 1 p.m. and 7 p.m., respectively. Rainfall in the " Yard ", recorded by the estate authorities, was 23·48 inches of which half fell in the first two weeks of the period, but rain actually fell on 37 days. This was the dry season.

Experimental Treatment.

A small hand-powered air pressure sprayer (Banner No. 22) was used. It was of cylinder type, without pressure gauge, capacity 1½ gallons (1·8 American), and fitted with 2-foot hose and 2-foot metal nose piece with trigger at base. The hose was lengthened to about 12 feet for use. The nozzle was of disk type with small central delivery hole. The jet was circular in form, reaching about 3 feet (at the pressure used). Since no gauge was available, we arrived at a suitable working pressure by trials of varying numbers of " pumps " of the pressure piston. The most suitable was 75 " pumps ". With this initial pressure the sprayer would deliver nearly its full charge. Pressure was maintained during operation by periodical pumping, but, of course, it varied considerably. In spraying rooms it was necessary to employ one man on the pump and hose and one man operating the nozzle.

The DDT used contained 72 per cent. of para-para isomer manufactured by Geigy Co. Ltd., Manchester, September, 1944. It was applied in kerosene at a concentration of 4·6 per cent.; 5 per cent. would not dissolve, 0·4 per cent. sludge remaining. The dosage attempted was 2 quarts per 1,000 sq. ft., but approximately 2·4 quarts was delivered. The estimated loss through drift of very small droplets or rebound from surface under treatment (*i.e.*, lost on floor or carried away by breeze) was 10 to 15 per cent. Probably 2·05 quarts per 1,000 sq. ft. (*i.e.*, approximately 106 mg. crude DDT per sq. ft.) was applied.

Inside surfaces only of rooms were sprayed—walls and roofs—all furniture, including beds (if any). In some rooms there were bits of sacking or other material over beds to catch droppings from the roof and in a few there were mosquito nets, usually in very bad condition. Some rooms were divided by low temporary partitions into two. All such surfaces were treated. It was estimated that room surfaces averaged approximately 800 sq. feet.

Costs.

One European (usually A.B.H.) and 2 local staff conducted the spraying. Since the sprayers used were unsuitable for work in high-roofed rooms with no ceilings, it was necessary to have one operator who could spray from a small ladder or more usually from the rafters themselves. It must be emphasised that high roof surfaces were reached only with great difficulty and were consequently not treated as thoroughly as we had hoped. There was much loss of the finer

droplets aimed at the roof because of the strong breeze blowing through the eaves of all buildings. Usually one operator sprayed the lower walls, a second man dealt with the roofs and dividing partitions and a third man attended the pump and its hose.

Time spent on spraying averaged 3 hours per 20 rooms but much of this was taken up in moving from one room to another.

Cost per 100 *rooms.*

Labour at say 30 dollars per month would be approx. 6 dollars or	25*s*. 0*d*.
48 gallons of kerosene at approx. 9*d*. per gall. customs free	36*s*. 0*d*.
24 lbs. of DDT at say 4*s*. 0*d*.	96*s*. 0*d*.
Labour and material per 100 rooms	157*s*. 0*d*.

The labour cost is based on the assumption that three local staff would be employed as they would be in future work.

Depreciation of the sprayer has not been estimated but it is considerable on the unsuitable type used. A more robust type with oil resistant hose must be produced.

Assessment of Effects of Treatment on Mosquitos in Bedrooms.

(i) *By Hand captures.*

The total number of mosquitos captured are shown in Table III. Reduction in the treated rooms varied between 99·3 and 94 per cent. over the seven weeks. There was an obvious reduction in the galleries. Although these were not sprayed, they were considerably contaminated by spray drifting from the rooms. Percentage weekly reductions based upon the two controls are given in Table IV.

TABLE III.

Lusignan.—Weekly totals of mosquitos (all spp.) captured by hand in sample rooms.

Week	No. of daily captures	8 rooms in control ranges			8 rooms in treated ranges		
		Total	In rooms	* In gallery	Total	In rooms	* In gallery
				Before treatment			
1st	6	(*b*) 751	711	40	(*a*) 693	664	29
				After treatment			
1st	6	1137	1109	28	7	2	5
2nd	6	1657	1629	28	6	2	4
3rd	6	1041	1037	4	5	4	1
4th	6	1536	1501	35	10	4	6
5th	6	1531	1507	24	19	5	14
6th	5	924	890	34	15	8	7
7th	5	883	842	41	36	35	1

* Galleries were not treated.
(*a*) Captures by hand before treatment in the treated ranges.
(*b*) Weekly captures by hand in control ranges.

TABLE IV.

Lusignan.—Gross weekly reductions expressed as percentages of (*a*) and (*b*) *see* above.

Weeks after treatment.

	1st	2nd	3rd	4th	5th	6th	7th
(*a*)	99	99·2	99·3	98·6	97·3	97·4	94·0
(*b*)	99·4	99·6	99·5	99·3	98·7	98·3	95·9

Analyses of captures in the sprayed and control ranges are given in Tables V and VI. At the dosage applied, DDT seems to be less effective against *C. fatigans* than against *A. darlingi*. The data for resting sites in the rooms are too scanty to be of significance.

TABLE V.

Lusignan—Analyses of total hand captures in 8 sample rooms of treated ranges.

Week	Total mosquitos (all spp.)	*A. darlingi*		*C. fatigans*		*Mansonia* mostly *titillans*		*Aëdes aegypti*	
		♂	♀	♂	♀	♂	♀	♂	♀
				Before Spraying					
1st	693	4	645 (93·6%)	4	30 (5·0%)	0	7 (1·0%)	0	3 (0·4%)
				After Spraying					
1st	2	...	...	...	2	...	...	...	...
2nd	2	...	...	...	2	...	...	...	...
3rd	4	...	...	...	4	...	...	...	...
4th	4	...	3	1	...	...	...	...	...
5th	5	...	4	...	1	...	...	...	...
6th	8	...	...	3	5	...	...	...	...
7th	35	...	...	14	21	...	...	...	...
	60	...	7 (11·7%)	18	... (88·3%)	...	...	...	...

After treatment of rooms 3 mosquitos were found on clothing hanging on walls, 6 under beds, 1 under tables and 34 on walls.

TABLE VI.

Lusignan—Analyses of total hand captures in 8 sample rooms of control range.

Week	Total mosquitos (all spp.)	*A. darlingi*		*C. fatigans*		*Mansonia* sp.		*Aëdomyia*		Unidentified
		♂	♀	♂	♀	♂	♀	♂	♀	
				Before treatment.						
1st ...	751	1	682	12	44	2	8	...	...	2
				After treatment of other ranges.						
1st ...	1137	4	1060	9	51	0	3	...	...	10
2nd ...	1657	2	1618	4	29	0	3	0	1	...
3rd ...	1041	1	995	2	16	0	22	0	2	3
4th ...	1536	9	1514	0	8	0	5	...	...	...
5th ...	1531	6	1195	1	43	0	12	0	3	271
6th ...	924	7	808	27	54	2	3	...	...	23
7th ...	883	3	649	23	95	0	1	...	...	112

(ii) *By "Flit" captures* (by the method mentioned on p. 401).

Only in one room (No. 19) were flit captures made both before and after treatment. The controls, therefore, were parallel captures in untreated rooms. Captures in treated and untreated rooms are given in Table VII. The difference between them suggests a reduction in treated huts of about 97·9 per cent. for all mosquitos and 99·7 per cent. for *A. darlingi* females, over eight weeks.

TABLE VII.

Lusignan—Total mosquitos captured after flitting in treated and untreated rooms, over eight weeks.

No. of samples	Total mosquitos	Average per capture	*A. darlingi*		*Culex fatigans*		*Mansonia*		*Aëdomyia squamipennis*		*Aëdes aegypti*	
			♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Untreated: 42	5021	119·5	27	4073	153	580	0	153	0	7	10	18
Treated: 40	102	2·5	3	11	22	58	0	7	0	1	0	0

Total flit captures of all species of *A. darlingi* in rooms of adjacent ranges, sprayed and unsprayed, are given in Table VIII. The apparent reduction is obvious. Details of other species have been omitted as being of little, if any, significance.

TABLE VIII.

Lusignan—"Flit" captures of all mosquitos and of *A. darlingi* in rooms of adjacent ranges.

Week	Control ranges			Treated ranges		
	No. of rooms	Total mosquitos	Female *A. darlingi*	No. of rooms	Total mosquitos	Female *A. darlingi*
			Before treatment.			
1st	1	327	217	1	227	197
			After treatment.			
1st	...	...	...	...	...	...
2nd	3	97	90	2	0	0
3rd	4	437	384	5	7	1
4th	6	604	553	6	7	4
5th	6	738	678	6	8	2
6th	5	456	376	5	6	0
7th	4	979	752	3	17	0
8th	4	337	173	4	16	2

Table IX shows captures in room 19 of range 11-20 in detail. Reduction here of *A. darlingi* females is about 98·5 per cent. on the 54th day after treatment. Reduction of *C. fatigans* females is about 77 per cent. in the same period and other species which in normal captures occurred in small numbers had not reappeared.

TABLE IX.

Lusignan—" Flit " Captures in Room 19 (Range 11–20).

Days	Total (all spp.)	*A. darlingi* ♂	*A. darlingi* ♀	*C. fatigans* ♂	*C. fatigans* ♀	Others
			Before treatment.			
7	127	2	76	12	34	1 ♀ *Aëdes aegypti* 2 ♀ *Aëdomyia*
1	227	0	197	0	26	1 ♀ *A. aegypti* 2 ♀ *Mansonia*
			After treatment.			
7	0	0	0	0	0	
15	5	0	1	0	3	1 ♀ *Mansonia*
26	5	0	3	1	1	
33	2	0	0	2	0	
43	6	0	0	1	5	
54	11	1	2	1	7	

(iii) *By DDT-Kerosene solution applied with a flit-gun.*

An attempt was made to apply an effective dose of DDT to the walls and ceiling of a cottage bedroom with a medium-sized Hudson flit gun. It was very tiring work; the spray was so fine that one had to direct it repeatedly at each portion of the surface in order to obtain what seemed to be an adequate deposit. The amount delivered was at the rate of 50 mg. of crude DDT per sq. foot. Much of this was lost, however, through drift of fine particles both before and after striking the wall surfaces. (Many flit guns deliver a spray that is much too fine for residual applications of low concentrations.)

Results for the first fortnight or so, after spraying, were quite promising with regard to *A. darlingi*, but not so good for *C. fatigans*. The occupants were disappointed, and of the opinion that because they were still seriously disturbed by mosquitos at night, the treatment was useless.

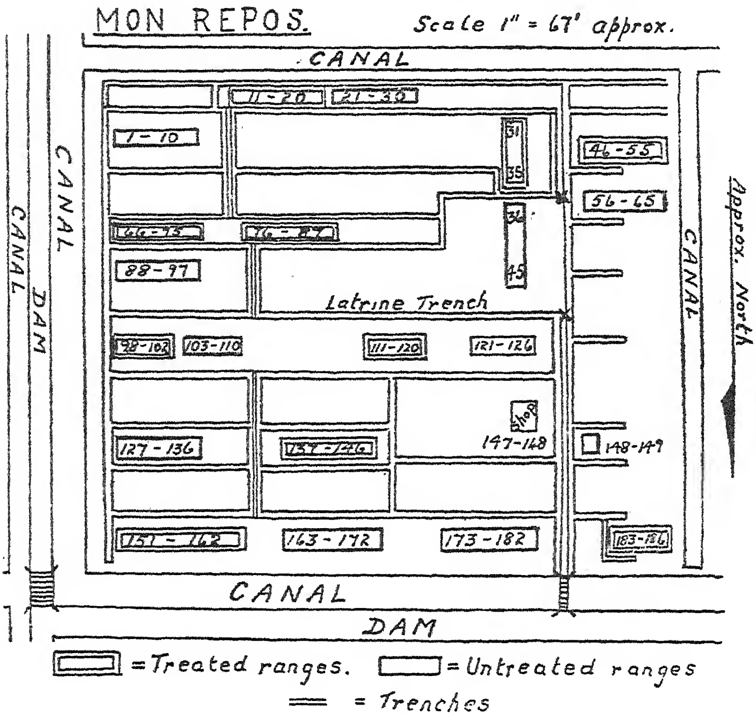
Where *C. fatigans* or other species are a major source of discomfort as they are here, it is obviously desirable to apply a dosage that will deal with them.

Mon Repos.

General conditions, layout and surroundings of this plantation are essentially similar to those described for Lusignan, and it is not thought necessary to include a plan of the estate and surroundings. The " yard " however, and its population, are very much smaller (Plan III).

A total of about 220 adults and 160 children, mostly East Indians, lived in the 20 ranges and 2 " cottages ".

In a survey conducted in March, 1945, Dr. Giglioli recorded the following high incidence of malaria.



Plan III.

No. of children examined	... ...	68	
,, ,, ,, with enlarged spleens	... ...	48	= 70 per cent.
,, ,, ,, ,, blood parasites	... ...	27	= 40 per cent.
,, ,, ,, ,, *P. vivax*	... ...	12	
,, ,, ,, ,, *P. falciparum*	... ...	8	
,, ,, ,, ,, undifferentiated rings	...	5	
,, ,, ,, ,, gametocytes	... ...	3	= 4 per cent.

Experimental Treatment.

Two sprayings were conducted in this area (Pl. VIII, figs. 3, 4). In the first, 85 rooms were sprayed in the same way as those at Lusignan (*see* page 405). Detailed observations on mosquito incidence in treated and untreated huts were made for a month and then all untreated rooms in the compound were sprayed. The effect on mosquitos is being ascertained by daily observations in selected huts, with captures in the adjoining village of Triumph as a control. Effects on malaria are to be ascertained later by Dr. Giglioli.

In the second, the sprayer used was a Briggs & Stratton ½-h.p. motor sprayer with gear pump and relief valve (on loan from the U.S. Govt. Dept. of Agriculture and Quarantine, Orlando, Florida). The relief valve was set to give 50-lbs. pressure which gave the most suitable " jet ". Hose, adequate, about 50 feet in length. Delivery, ½ gallon in 3 minutes. Jet, linear in form; middle droplets fine, edges coarse and wetting; much of the fine portion floating away as mist. The nozzle is circular, with central exit hole in the middle of a cut across the external disc; it is apparently this cut that produces the linear jet of fluid. The nozzle is not adjustable. The rate of operation averaged about 6 minutes per room for 80 rooms. This includes all activities connected with the operation, such as moving the outfit and refilling reservoir. The engine ran well and gave no trouble. Fuel consumption is very low—about 1 quart in 3 hours.

Three men were employed—one on the engine and its hose and two actually spraying. It is probable that two could manage though it is safer with three and the third provides much needed relief for the sprayers.

The solution applied was 4·6 per cent. in kerosene. The dosage was the same as for Lusignan—approximately 2 quarts per 1,000 sq. feet.

In this second operation it was decided that both the room and the gallery or verandah which ran the whole length of each range (or block) must be treated since appreciable numbers of mosquitos harboured in the galleries and attacked people occupied with domestic activities. Since the galleries usually contain kitchens, wood " bins ", drums and an astounding amount of other domestic litter they add appreciably to the surfaces to be treated, and to the work.

The galleries and their contents were estimated to average 200 sq. feet for treatment bringing the total surface area per room to 1,000 sq. feet.

Costs of spraying per 100 rooms (including galleries).

Labour	17*s*. 0*d*. approx.
Solution—DDT—25-lbs.	100*s*. 0*d*.
Kerosene 50 gallons	37*s*. 0*d*.
	154*s*. 0*d*.

The depreciation of the sprayer has not been estimated. It is probably very small since the engine maintains a suitable pressure at low speeds, and leather washers appeared to be the only spares likely to be needed for a considerable working life. The hose is oil resistant.

Assessment of Effects of Treatment on Mosquitos in Bedrooms.

The effect of the treatment on mosquitos as indicated by hand captures is shown by comparing Tables X and XI with XII and XV.

Briefly, reduction of all species in the treated ranges over 6 weeks varied between 100 and 99 per cent., and of *A. darlingi* females between 100 and 99·4 per cent. *C. fatigans* showed an increase in relation to *A. darlingi* after spraying.

TABLE X.

Mon Repos—Hand captures in treated and untreated ranges.

Week	No. of daily captures	10 Rooms in untreated ranges			Rooms in treated ranges		
		Total all spp.	No. in room	No. in gallery	Total all spp.	No. in room	No. in gallery
			Before treatment.				
1st	6	677	594	83	925	763	162
2nd	5	398	366	32	496	452	44
			After treatment.				
1st	6	967	811	156	0	0	0
2nd	6	430	376	54	6	6	0
3rd	6	359	337	22	6	5	1
4th	6	387	387	0	3	3	0
5th	6	545	545	0	6	5	1
6th	6	*	...	...	0	0	0

* Spraying of all untreated ranges was done at this time.

" Flitting " captures of treated and untreated rooms are shown in Tables XIII and XIV and the " Triumph " control houses in Table XVI. They indicate a reduction in all mosquitos, and in *A. darlingi*, of about 99·75 per cent.

TABLE XI.

Mon Repos—Analyses of hand captures in 10 sample rooms of treated ranges only, before and after treatment.

Week	Total all spp.	*A. darlingi*		*C. fatigans*		*Mansonia* spp.		*A. aegypti*		Others
		♂	♀	♂	♀	♂	♀	♂	♀	
				2 weeks before treatment.						
	1,421	7	1,320	2	40	0	39	1	8	*A. albitarsis* 1 ♀. *A. aquasalis* 1 ♀. *Aëdes taeniorhynchus* 1 ♀. *Aëdomyia squamipennis* 1 ♀.
% of total captures		0·5	92·9	0·1	2·8		2·8		0·6	
				After spraying.						
1st	0	...	...	...	...	...	...	...	...	
2nd	6	1	3	0	1	0	1	...	...	
3rd	5	0	4	0	0	0	1	...	...	
4th	3	0	3	...	...	...	...	...	...	
5th	5	0	0	2	1	0	2	...	...	
6th	0	...	...	...	...	...	...	...	...	
	19	1	10	2	2	0	4	...	...	
% of total captures	...	5·3	52·6	10·5	10·5	...	21·0	...	...	

After treatment of rooms 1 mosquito was found on clothing, 1 on curtains over beds, 1 under tables, 8 under beds, 3 on walls and 1 flying in room.

TABLE XII.

Mon Repos—Analyses of hand captures in 10 sample rooms of control ranges.

Week	Total mosquitos all species	*A. darlingi*		*C. fatigans*		*Mansonia* mostly *titillans*		Other species
		♂	♀	♂	♀	♂	♀	
			Before treatment					
1st	677	5	619	4	27	0	9	11
2nd	398	0	385	2	8	0	2	1
			After treatment of other ranges					
1st	967	2	939	0	12	0	12	2
2nd	430	0	404	2	3	0	9	12
3rd	359	3	340	0	3	0	3	10
4th	387	0	385	0	1	0	0	1
5th	545	3	521	1	9	0	9	2
All control ranges then treated								

TABLE XIII.

Mon Repos—Total " flit " captures of adults in bedrooms, over six weeks.

	No. of samples	Total all spp.	Average	*A. darlingi*		*C. fatigans*		*Mansonia* spp.		*Aëdomyia squamipennis*		*A. aegypti*		Others
				♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	
Control Ranges	30	1557	51·9	18	1,386	15	53	0	52	0	5	3	4	21*
Sprayed Ranges	30	4	0·13	0	3	0	0	0	1	...	...	...	...	...

* Unidentified.

TABLE XIV.

Mon Repos—" Flit " captures before and after treatment in Room 31.

Date	Days before treatment	Total	*A. darlingi*		*Culex fatigans*		*Mansonia* spp.		*Aëdomyia squamipennis*	
			♂	♀	♂	♀	♂	♀	♂	♀
14.ii	9	81	0	70	0	2	0	8	0	1

Up to 40 days after treatment no captures were made.

Triumph Village (Control).

Triumph village is a collection of cottage-type houses occupying an old sugar estate, about 250 yards west of Mon Repos. The main canals and drains remain. A considerable amount of vegetation including coconut, palm and other trees has grown up around the houses.

All the houses used were on the eastern edge of the village along a canal. They were all, except one, constructed of wood, on piles from 4 to 6 feet high, and in fairly good repair. The exception had mud walls and thatch roof. One of the wooden houses had a roof of thatch and two had wood; the remainder had corrugated iron. Occupants were all East Indians.

Observations were conducted here, to furnish a control for Mon Repos after the treatment of all ranges in late March and early April. The record of captures is given in Tables XV and XVI. The greater value of " flit " captures is again shown in Table XVI.

It may be of interest to record that the biggest captures by hand were made in a house with good bait and a dark roof (No. 4) and in two others with thatched roofs (5 and 7); and that the highest catches came from No. 5 which had mud walls.

Examinations were made of samples of live adults collected in houses. Of 6,925 female *darlingi* examined only 71 were unfed. In 1,957 dissected, only 2 had infected glands and 62 were unfertilised. These figures have little, if any, significance now but they might be of use if collection is continued. Ages of mosquitos and infectivity rates should decrease with numbers, if the insecticide is having an effect.

TABLE XV.

Triumph Village—Hand captures of adults in 10 houses

Week	No. of daily captures	Total mosquitos all species	*A. darlingi* ♂	*A. darlingi* ♀	*C. fatigans* ♂	*C. fatigans* ♀	*Mansonia titillans* ♂	*Mansonia titillans* ♀	*Aëdomyia* ♂	*Aëdomyia* ♀	Others
				Before treatment of Mon Repos							
1st	6	955	0	833	3	48	0	9	0	2	60
2nd	5	1010	1	898	7	102	0	1	0	1	...
				After treatment of Mon Repos							
1st	3	477	3	430	2	6	0	2	0	0	34
2nd	No	catch									
3rd	4	394	1	356	12	19	0	0	2	4	...
4th	6	893	12	672	61	108	0	28	2	8	2
5th	2	465	10	393	17	29	0	14	0	2	...

TABLE XVI.

Triumph Village—"Flit" Captures.

Date	House No.	Routine hand catches	Flit capture	*A. darlingi* ♂	*A. darlingi* ♀	*C. fatigans* ♂	*C. fatigans* ♀	*Mansonia* sp. ♂	*Mansonia* sp. ♀	*Aëdomyia squamipennis* ♂	*Aëdomyia squamipennis* ♀
21.iii	1	6	12	0	4	5	2	...	...	0	1
19.iii	2	7	33	0	29	0	2	0	2	...	...
16.iii	4	23	191	0	173	2	11	0	3	1	2
6.iv	4	22	136	0	99	9	16	0	6	0	6
16.iii	5	22	254	0	193	5	56	...	...	...	...
9.iv	5	40	90	0	46	19	18	0	7	...	...
19.iv	7	10	44	0	32	2	7	0	3	...	...
7.iv	7	not made	28	1	27	...	...	...	...	...	...
23.iii	8	4	63	0	51	0	5	7	6	...	...
23.iii	9	0	3	0	1	0	2	...	...	...	...

La Grange.

Experimental Treatment.

La Grange is essentially a rice growing area. The population, most of whom are East Indians, are small rice farmers. Houses here were of various types—some were of mud and thatch and not raised on piles, others were of wood with wood or "iron" roofs, raised on piles. They were situated along each side of a road with side canals, and separated one from another by distances varying from a few to about 100 yards.

The area was selected for small scale trials. The following five solutions were tested and in each case five houses were treated:—

(i) 19/iii/45—5 per cent. DDT in hydrocarbon oil and kerosene at a dosage of 2 quarts per 1,000 sq. feet (100 mg. DDT per sq. foot).

(ii) 19/iii/45—5 per cent. DDT in hydrocarbon oil and kerosene at a dosage of 4 quarts per 1,000 sq. feet (200 mg. DDT per sq. foot).

(iii) 19/iii/45—2½ per cent. DDT in hydrocarbon oil and kerosene at a dosage of 2 quarts per 1,000 sq. feet (50 mg. DDT per sq. foot).

(iv) 20/iii/45—6 per cent. DDT emulsion at a dosage of 2 quarts per 1,000 sq. feet (120 mg. DDT per sq. foot).

(v) 21/iii/45—Kerosene only at a dosage of 2 quarts per 1,000 sq. feet. The kerosene was of the same type as that used in all our kerosene solutions.

For experiments (i) to (iv) inclusive the small hand-powered sprayer previously described was used (*see* Lusignan). The kerosene treatment was applied with a Myers (No. 1331 "New Idea") knapsack sprayer of ordinary type with side hand-pump, a short length of hose and metal nose piece with trigger at the base. The nozzle was of the usual circular disk pattern with small central hole delivering a rather wetting jet some 2 or 3 feet. As with other apparatus a good deal of fluid was lost in the form of too heavy or too light droplets.

Solutions were made up as follows:—

(i) 5 per cent. DDT in hydrocarbon oil and kerosene.*

9 lbs. of DDT were dissolved in 3 gallons of hydrocarbon oil 544A and 15 gallons of kerosene added. Stored in tins from 12/iii/45 until 19 and 20/iii/45.

(ii) 2½ per cent. DDT.

3 gallons of the above solution (ii) were diluted with 3 gallons of kerosene. Stored in tins from 12/iii/45 until 19/iii/45.

(iii) 6 per cent. DDT Emulsion.

800 grams of DDT were dissolved in 2,080 cc. of rectified Xylene on 12/iii/45. Shaken at intervals and filtered on 15/iii/45. 42 grams of insoluble sediment was obtained. 320 cc. of Triton X 100 were added to give a 25 per cent. solution of DDT. This concentrate was stored in glass bottles until 20/iii/45. It was then diluted with 4 times its volume of water and used immediately.

All internal surfaces were treated. These included bed and other rooms, verandahs (or galleries), kitchens and other compartments under the one roof and, of course, ceilings—or more properly the under surfaces of roofs—some of which were of leaf thatch.

The houses here are not so high as the ranges of Lusignan and Mon Repos and less difficulty was experienced in reaching the higher portions. Nonetheless an appreciable loss of fluid on floors and through eaves could not be avoided. It was probably somewhat less than 5 per cent.

Costs.—Since only small amounts of a variety of solutions were employed, details of costs would probably be of little practical use. The following brief notes may help, however, in planning future operations in similar areas.

(i) Staff.—Three men were employed—one European (A.B.H.) and two Guianese. Two could well do the spraying and attend to the spray-pump, but considerable distances have to be covered and the equipment has to be carried. It would be possible to employ a small hand-cart in which case two men could manage.

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* Kerosene supplied by the Esso Standard Company, Georgetown, from stocks imported from Trinidad. Refined in Trinidad.

A power sprayer with wheels would not be suitable because of the many narrow bridges giving access to houses across the canals. The small outfit used at Mon Repos in April, however, would appear to be suitable for this type of area.

(ii) Time spent in operations was longer per house than at the two estates because of the considerable distances between houses. Detailed notes of the time spent in getting from one house to another were not made but it probably averaged about 10 minutes. Spraying took 8-10 minutes. Average time spent per house was, therefore, about 20 minutes.

Assessment of Effects of Treatment on Mosquitos in Houses.

Mean daily "flit" captures are given in Table XVII. These together with the captures in individual houses (not shown here) indicate the following points:—

(i) House populations were low, especially of *A. darlingi.*

(ii) There was a general natural reduction of mosquitos over the five week period though the high proportions of male *C. fatigans* (not shown here) during the first three weeks of the treatment suggested that a considerable output of that species, at least, continued.

(iii) 6 per cent. DDT emulsion at 2 quarts per 1,000 sq. feet.
This had, apparently, a good effect against *A. darlingi* but a poor action on *C. fatigans* in a wood and thatched hut and in an iron roofed hut with whitewashed walls. The latter, occupied by an old man, was particularly dirty and unkempt.

(iv) $2\frac{1}{2}$ per cent. DDT solution in kerosene at 2 quarts per 1,000 square feet.
Fairly good against *A. darlingi* in all huts, but poor against *C. fatigans* in a mud and thatch hut and little better in a wooden hut with thatched roof. This weaker solution seems to be roughly as effective as the 5 per cent. solution and 6 per cent. emulsion over a four week period. It remains to be seen from later observations how its toxicity will last.

(v) 5 per cent. DDT solution at 2 quarts per 1,000 sq. feet.
Effective against *A. darlingi* in all huts, but poor against *C. fatigans* in a papered hut and in a hut with mud and palm thatch.

(vi) 5 per cent. DDT solution of 4 quarts per 1,000 sq. feet.
This also was effective against *A. darlingi* but not so effective against *C. fatigans,* specially in a painted wood and iron hut.

(vii) *C. fatigans* shows more resistance than *A. darlingi* to DDT.

(viii) Mud walls, thatched roofs and painted or whitewashed wood all appear to have reduced the efficacy of the treatments against *C. fatigans.* It is not clear whether this is due to irregular distribution and perhaps deep absorption of the solutions on the mud and thatch or to some unknown action of the paint and whitewash and to perhaps a loss of DDT residue as dust falling from the whitewashed wall.

(ix) Captures in houses treated with kerosene only are not shown. They indicated that kerosene had no apparent effect after the first 24 hours. It may be well to emphasise that the work is incomplete; observations must go on for some time to produce useful conclusions.

TABLE XVII.

La Grange—Mean daily "flit" captures per house.

Application per 1000 sq. ft.		Week before treatment	After treatment			
			1st week	2nd week	3rd week	4th week
Control Houses.	Total	71·0	64·3	51·7	45·0	10·7
	A. darlingi	11·0	14·3	12·0	9·0	3·0
	C. fatigans	60·0	50·0	39·7	36·0	7·7
6% *DDT Emulsion 2 qts.*	Total	125·0	3·2	2·7	10·2	11·2
	A. darlingi	54·5	0·2	0	0	0·2
	C. fatigans	70·5	3·0	2·7	10·2	11·0
2½% *DDT in kerosene 2 qts.*	Total	135·5	5·7	3·0	2·8	5·2
	A. darlingi	44·7	0	0·2	0·2	0
	C. fatigans	90·8	5·7	2·8	2·6	5·2
5% *DDT in kerosene 2 qts.*	Total	65·7	3·7	4	1·2	1·2
	A. darlingi	31·7	0	0	0	0
	C. fatigans	34·0	3·7	4	1·2	1·2
5% *DDT in kerosene 4 qts.*	Total	52·5	1·6	7·0	20·2*	3·8
	A. darlingi	37·5	0·2	0	0	0
	C. fatigans	15·0	1·4	7·0	20·2	3·8

* Includes 80 *Culex* in one house.

Lodge Village.

Lodge Village is a suburb of Georgetown, situated just over a mile from the centre of the town. Houses number 583; population about 2,500. Houses are of wood, on wooden piles usually about 4-6 feet high. The majority are small two or three-roomed structures in varying stages of disrepair but a few are larger. They are arranged along three parallel roads or streets about 1,300 yards long running roughly east and west. A few short side roads link up the three main streets. Distance between streets is about 150 yards. Hadfield Street, the most northerly, has one row of houses on its southern side, D'Urban Street in the middle has two rows, and Princes Street on the south has one row on its northern side. Many houses occur on intermediate sites.

The area immediately south of the village is a cemetery, most of which is covered by low scrub and grass, but there are a few trees and palms. Further south is La Penitence, an old sugar estate now used for rice fields and gardens, and still further is Ruimveldt sugar plantation.

Over all the area are the usual large canals and very numerous drains. There are scrub, some large trees, a few thick bushes, long grass and, in the most southerly portion, 8 ft. high sugar cane. In the village itself between the houses, vegetation (trees and bushes) is fairly dense.

Malaria incidence is high. Dr. Giglioli recorded a spleen rate of 67 per cent. and a parasite rate of 85 per cent. in children last year. (Results of his most recent survey are not yet available.)

Filariasis is also very common and elephantiasis is unusually obvious.

Mosquito production in the many miles of canals and drains in the village and in the country to the north, east and south is high. In the village itself a considerable number of pools contribute largely to mosquito output, and pit latrines, a few feet deep, are responsible for large numbers of *C. fatigans,* Wied.

Species recorded during the investigation, as larvae or adults, included *A. darlingi,* Root, *A. albitarsis,* Arrib., *A. triannulatus,* Neiva & Pinto, *A. aquasalis,* Curry (= *tarsimaculatus,* auct.), *C. fatigans, Mansonia titillans,* Wlk., *M. fasciolata,* Arrib., *Aëdomyia squamipennis,* Arrib., and some undetermined Culicines.

A. darlingi and *C. fatigans* were most commonly found in houses, the former in small numbers (during the period of the investigations), the latter in large numbers. Up to 1,462 *C. fatigans* were recorded in a single catch in a bedroom.

Experiment with Thermal Generator (6–10.30 p.m. on 12.iv.45)*

"(i) The Hochberg-LaMer generator is an apparatus in which an aqueous emulsion of an oil (in which the insecticide has been dissolved) is pumped under pressure through appropriate flow-control apparatus into a heater coil, *where the water but not the oil is vaporised.* The mixture of water vapour and liquid oil under pressure is discharged into the atmosphere through cylindrical nozzles during which process the oil is broken up into particles of 1 to 10 microns radius. The average particle radius and the variation of particle sizes depend upon the choice of operating variables.

The Hochberg-LaMer aerosol generator used in Lodge Village had an output capacity of 15-20 American gallons of emulsion per hour. The generator was mounted on a lorry together with the emulsion drums.

(ii) *Emulsion.*—The emulsion had the following composition:—

Lubricating oil (containing 2% Tween 85)	*Xylene*	*Water*	*DDT*
50 parts	17 parts	44 parts	7·5 parts

(*i.e.,* approximately 7% DDT)

The Xylene was used to lower the viscosity of the Teresso 43 lubricating oil, and to make possible a more concentrated solution of DDT in the oil. Assuming the experimental area to have a depth of 8,000 feet on a front of 1,000 feet, dosage was at the rate of 0·18 lbs. of DDT per acre.

(iii) *Operating conditions.*—The generator was operated with a nozzle temperature of 450° F. and a nozzle pressure of 70-80 lbs. sq. inch. Operation at these conditions produced an aerosol with a mass average particle radius of between 4 and 5 microns. This was checked before the test using oleophobic slides.

(iv) *Time of test and output.*—The test was carried out between the hours of 6·00 hours and 10·30 p.m. on Thursday, 12th April, 1945. The following table gives the outputs on each street, and time of operation.

	Time of operation	*No. of trips over 1,000′ front*	*Output (gals. of 7% emulsion)*
Hadfield ...	6·05-6·50	3	13·5
D'Urban ...	6·55-7·50	2	16·5
Princes ...	8·10-10·30 (20 min. stop in this street)	7	30

* **Written by Messrs. K. C. Hodges and J. Rowell, of Columbia University, New York.**

The total output was 67 American gallons, and it is estimated 7 gallons were expended travelling from D'Urban to Princes Street.

(v) *Meteorology.*—The prevalence of storms during the day before the test and on the day of the test changed the usual wind characteristics for Demerara. At the start of the test the wind direction was estimated to be E.N.E. at the generator with gusts from N.E. to E. The velocity at the generator at 6 p.m. was 300 feet per minute (4 m.p.h.).

As the test progressed the wind velocity decreased further and occasional gusts from E. and E.S.E. were noticed.

Inversion was good at the beginning of the test. The aerosol drifted through and between the houses with an upper ceiling of about 20 feet. Observation of the aerosol was difficult later but it is unlikely there was any appreciable change in the inversion."

An attempt was made to assess results by:—

(i) surveys of natural breeding grounds;
(ii) distribution of fourth-stage larvae of *A. darlingi* in pans over the area;
(iii) routine hand captures of adult mosquitos in houses of Lodge Village;
(iv) "flitting" captures of adult mosquitos in bedrooms;
(v) captures of adults in natural harbourages by the use of a "drop" net;
(vi) distribution of *A. darlingi* in small cages over the area.

Our observations after treatment were very incomplete owing to our early departure from British Guiana.

Effect on natural breeding.

Facilities for breeding were abundant owing to the numerous canals, cross canals and drains.

In the surveys conducted between 26th February and 12th April the breeding grounds shown in Table XVIII were recorded and labelled. This was a small sample of the total breedings.

A combination of religious holidays and other factors interfered seriously with surveys after the treatment, and the data obtained were quite inadequate to permit of any conclusion as to effects on natural breeding. From the few general observations made it seems that at least third- and fourth-stage Anopheline larvae were killed in the Lodge Village and Cemetery areas to a distance of about 2,000 feet from the generator. It is probable that this effect extended much further.

First- and second-stage larvae, but few larger, were recorded in all areas from the 14th onwards; that is 48 hours or so after treatment. These, or some of them, may have been survivals but many were probably new hatchings.

TABLE XVIII.

Breeding Places.

Area	No. of searches	No. positive	No. with					
			A. darlingi	*A. aquasalis*	*A. albitarsis*	*A. triannulatus*	*C. fatigans*	*Aëdomyia squamipennis*
Lodge Village ...	52	50	7	12	15	2	37	17
Cemetery (Le Repentir)	190	143	25	17	8	13	60	75
La Penitence ...	15	15	4	5	3	3	11	0
Ruimveldt ...	22	22	9	7	2	4	16	1

Effect on larvae of A. darlingi exposed in pans.

Small basins of about 6 in. diameter and some 2 in. deep, each containing 10 fourth-stage larvae reared in the laboratory, were distributed over a wide area from Lodge Village through the Cemetery to La Penitence and Ruimveldt beyond. They were exposed from about 3·30 to 5 p.m. on 12th April to 8 to 10 a.m. on 13th April.

The pans of larvae on the western edge of the area which it was thought would serve as controls were all affected by the treatment. In order to get a figure for "natural" deaths, therefore, twelve pans were put out on the nights of 17th and 18th April at Sophia—about a mile north-east of Lodge Village—in sites similar to those used for the experiment. They remained exposed from 3·30 p.m. until 8 a.m. the following morning on each occasion.

Results are shown in Table XIX, which gives the kills in the experiment, corrected for natural deaths as shown by the controls. This control is not, of course, strictly acceptable, but it was the best possible under the circumstances. The weather on the 17th and 18th was normal with a fair breeze and nothing unusual about temperatures.

Table XIX.

Kill of larvae of *A. darlingi* in pans.

—	No. of pans	No. of larvae exposed	No. of larvae dead	% dead	No. pupated	Corrected % kill
Lodge Village	12	119	119	100	...	100
Le Repentir (Cemetery) North ...	10	100	96	96	4	95·8
South	9	90	96	95·5	3	95·3
La Penitence—						
North	4	40	36	90	2	89·5
South	2	20	11	55	2	52·6
Ruimveldt						
North	6	56	55	98·2	1	98·1
South	6	56	56	100	...	100
Total	49	481	459	94	...	94·3

Control.

Sophia (17th)	12	120	8	6·6	14
(18th)	12	120	4	3·3	5
		240	12	5·0	

Assessment of effects of treatment on adult mosquitos in bedrooms.

(i) *By Hand Captures.* Table XX gives means of routine captures conducted over some three weeks before the trial. Tables XXI and XXII show reduction in numbers of mosquitos, as indicated by hand captures, in the few individual houses that were searched before and after treatment. These figures for hand captures compared with those for "flit" captures in Table XXIII indicate fairly clearly the inadequacy of hand catching as a measurement of mosquito room populations.

TABLE XX.

Lodge Village—Means of daily hand captures over three weeks.

Street	No. of rooms	Total mosquitos	*A. darlingi* ♂	*A. darlingi* ♀	*C. fatigans* ♂	*C. fatigans* ♀	*Mansonia* sp.
Hadfield	10	229	0	2·4	74·8	151·7	0·1
D'Urban	10	148	0	6·4	52·4	89·0	0·2
Princes	10	158	0	27·0	51·0	80·0	0

TABLE XXI.

Lodge Village—Hand captures in three individual houses.

	In treated area			Not in treated area but affected by drift through wind changes		
	Hadfield	D'Urban	Princes	Hadfield	D'Urban	Princes
	Before treatment					
Mean of 17 daily captures per bedroom	14·5	10·0	21·0	26·0	17·2	15·7
	After treatment (% reduction in brackets)					
Mean daily capture per bedroom 14·iv ...	0·3 (98)	1·0 (90)	4·3 (80)	4·7 (83)	7·0 (60)	6·7 (58)
Mean daily capture per bedroom 16·iv ...	2·0	0·7	2·7	9·7	6·7	2·3
Mean daily capture per bedroom 17·iv ...	2·0 (86)	...	5·0 (76)	10·7 (59)	...	8·7 (46)

TABLE XXII.

Lodge Village " Flit " Captures

(One bedroom of each house)

" Flit " captures were made an hour or two after hand captures.

Date	Street	House No.	Routine catch (by hand)	Total catch (by flitting)	*A. darlingi* ♂	*A. darlingi* ♀	*Culex* (mostly *fatigans*) ♂	*Culex* (mostly *fatigans*) ♀	Others
March									
15	D'Urban	3	46	1069	0	3	614	451	1 ♀ *Mansonia*
15	D'Urban	74	No catch	291	0	19	6	266	
16	D'Urban	3	140	732	0	0	557	175	
16	D'Urban	74	6	136	0	10	23	103	
17	Hadfield	28	23	358	0	1	204	153	
19	Hadfield	28	55	629	0	4	479	146	
20	Princes	17	No catch	473	0	19	43	411	
21	D'Urban	26	21	1169	0	1	835	332	1 ♀ *Mansonia*
23	Princes	14	No catch	1477	0	11	408	1054	4 ♀ *Mansonia*
23	D'Urban	36	"	850	0	0	613	237	
23	Hadfield	35	"	1323	0	4	561	758	

(ii) *By Flit Captures.* Results of "flit" captures before and after treatment are indicated in Table XXIII. After-treatment captures were too few to warrant a conclusion as to total effect on adults in houses but they indicate that over four days reductions in mosquitos varied between 78 and 99 per cent.

TABLE XXIII.

Lodge Village—"Flit" captures in individual houses (1 bedroom in each).

Street	House No.	Date	Total mosquitos per capture	*A. darlingi* ♂	*A. darlingi* ♀	*C. fatigans* ♂	*C. fatigans* ♀
Before treatment (26.iii.45 to 4.iv.45)							
Hadfield	63	29/iii/45	111	0	0	73	38
,, ...	42	26/iii/45	26	0	1	9	16
D'Urban	40	26/iii/45	304	0	24	0	280
Princes	28	30/iii/45	247	0	0	69	178
,, ...	38	4/iv/45	340	0	1	213	126
After (14.iv.45 to 16.iv.45)							
Hadfield	63	14/iv/45	0	0	0	0	0
,, ...	42	16/iv/45	3	0	0	0	3
D'Urban	40	14/iv/45	13	0	0	3	10
Princes	28	16/iv/45	54	0	2	3	49
,, ...	38	14/iv/45	17	0	0	8	9
,, ...	38	16/iv/45	21	0	2	1	18

Effect on adults of A. darlingi exposed in cages (Pl. VIII, fig. 6).

(i) *Lodge Village.* Some cages were suspended inside houses. Gardens and land between houses had fairly good growths of scrub and trees and cages with pans of larvae were placed in or amongst these. They were thus protected to some extent by 3-foot high bushes and 15-foot high trees.

(ii) *Le Repentir Cemetery.* Cages and pans were placed among and beneath bush from 3 to 10 feet high. Two cages were suspended on trees seven feet above ground and two at 12 feet and 15 feet respectively.

(iii) *La Penitence* consists mostly of rice fields and gardens. Cages were, therefore, exposed either in rice fields or on the low dams between them. Pans of larvae were placed in or beneath scrub or rice and on the sides of dams.

(iv) *Ruimveldt.* Cages were placed on the edges of canals and about 10 yards deep in the sugarcane which was mostly about 8 feet high. Pans of larvae were in the same sites.

All cages, except those hung on trees, were suspended from pegs (fitted with a band of oil-impregnated tow) about a foot above the ground. They were put out between 3·30 and 5 p.m. on 12/iv/45 and collected between 7 and 10 a.m. on 13/iv/46. The mosquitos used were reared by Dr. Giglioli and his staff in the laboratory. Though 10 specimens were put into each cage, not all of these were recovered as some were eaten by ants in spite of precautions. An appreciable proportion almost certainly escaped through the gauze which, it was discovered too late, was of too big a mesh. (This gauze is in widespread use in British Guiana for mosquito bed nets.)

Results are based on numbers recovered after exposure and not on numbers put into the cages. They are given in Table XXIV.

For controls, 5 cages with 51 adults were exposed at Sophia in various positions corresponding to those in the treated area.

Highest kills were obtained in Lodge Village (99 per cent.) and the northern block of Repentir Cemetery (90·5 per cent.). The four surviving specimens in the latter area were in a cage situated on the western edge of the treated area which probably got only a small dosage. The majority of survivors in the southern block of the Cemetery area (76·8 per cent. kill) were in cages sheltered by a 10 foot high bush.

In the two sections of La Penitence, at 2-4,000 feet from the generator kills were somewhat lower (79·8 per cent. and 60·0 per cent.). Survivors here were in two cages protected by the side of dams and in one by low bush. In another cage, suspended on a tree 5 feet above ground, there were three survivors. Kills were still lower in the Ruimveldt area. In the northern block at about 4,000 feet from the generator the kill was only 18 per cent. It was higher in the southern block (52·3 per cent.). Two cages were sited in spots that it was thought would be beyond the western edge of the drift but they both appeared to be affected as one had one death and the other 5. In the latter instance the cage was about 8,000 feet from the generator, on a grassy mound.

TABLE XXIV.

Adults of *A. darlingi*.

(Exposed from 5 p.m. 12/iv/45 to 8–10 a.m. 13/iv/45.)

	No. of sites	Mosquitos		%	
		No. exposed	No. dead after 18 hours	Death	Kill corrected for deaths in controls
Lodge Village					
In houses	12	120	118	98·3	98·1
Lodge Village					
Outside...	5	52	52	100	100
Le Repentir Cemetery					
North	5	48	44	91·6	90·5
South	10	73	58	79·4	76·8
La Penitence					
North	6	45	37	82·2	79·6
South	4	34	22	64·7	60
Ruimveldt					
North	6	50	14	28	18·1
South	6	50	29	58	52·3
Control					
Sophia...	5	51	7	14	

Recommendations.

Briefly the results of the test are very encouraging. There is little doubt that the method holds out great promise. But it is essential that further research and development be devoted to the following points:—

1. Simplification of the generator itself so that it can be handled by other than highly trained scientists.

2. Greater mobility of the generator to make possible its use in areas without roads or canals, as for instance, a machine that could be carried by two men or pushed on wheels along forest or other tracks that are unsuitable for motor vehicles.
3. The use of some solvent other than xylene or benzene. These highly inflammable agents are not usually very easily obtained in most tropical areas, and their transport presents some difficulties.

Other Observations.

Mosquitos collected in specially constructed observation Huts at Lusignan.

To facilitate a close study of species entering dwellings at night, and their reactions to a DDT application, two wooden, single-roomed, portable huts on wooden piles $2\frac{1}{2}$ feet high were constructed (*see* Plan II). Internal dimensions were 10 × 12 feet with walls 8 feet high and ceilings of dark cloth (No. 1) and hessian (No. 2). Eaves were left open and the ceilings were fixed just above them to permit entry by mosquitos. Muslin curtains were attached above the eaves. The huts were situated at the south-west corner of the West Yard, Lusignan, with doors facing east and shutters north and south; they were about 50 yards from the nearest cottage and 15 yards from the side canal.

Staff consisted of one European (A.B.H. or C.B.S.) and two Guianese collectors in each hut. Captures were made at intervals throughout the night when the doors and shutters were closed, and the muslin curtains dropped over the eaves. At all other times these were open.

For six nights—19th to 25th March—routine catches were made with very little variation in conditions except climatic, and in the human bait in the form of two additional sleepers in one or other of the huts. On the 26th March, No. 1 hut was treated with 5 per cent. DDT solution in kerosene at a dosage of 2 quarts per 1,000 sq. feet. Walls, ceilings and all furniture were sprayed and strips of white muslin were placed on the floor at the base of walls to facilitate the catch of immobilised specimens. Observations indicated that:—

(*a*) There are two optimum periods of mosquito activity which occur at dusk and dawn and last in each case usually for about 30 to 60 minutes. The dusk peak period may extend considerably.

(*b*) During these periods *Anopheles darlingi*, *Mansonia titillans* and *Culex fatigans* (*quinquefasciatus*) in large numbers, *Aëdomyia squamipennis*, an unidentified *Culex* and *Mansonia fasciolata* in moderate numbers, and *Aëdes taeniorhynchus* and *Anopheles albitarsis* in small numbers were encountered.

(*c*) Maximum entry of mosquitos to huts occurred between 7 p.m. and 12 p.m. (*see* Tables XXVII and XXVIII). This is particularly noticeable in the case of *Anopheles darlingi* and *Mansonia titillans*. Most of the few *A. albitarsis* entered after 12 p.m. and the majority appeared on the night of 23rd-24th after a heavy rain lasting from about 8 to 11 p.m.

(*d*) *Mansonia* (mostly *titillans*) entered steadily during the night but normally appeared to leave soon after feeding, since it was found in relatively small numbers in occupied rooms after daybreak (as shown by routine hand catches between 6 a.m. and 8·30 a.m.). In the observation huts during the first week it could not feed readily as the bait was protected by mosquito nets.

(*e*) *Aëdomyia squamipennis* appeared normally to leave most occupied rooms early in the morning, since, like *Mansonia*, it was found only in small numbers in morning routine catches.

(*f*) A large percentage of specimens of all species entering huts throughout the catching period were unfed. It seemed that by no means all the mosquitos managed to get their meal before daybreak.

(*g*) Appreciable numbers of mosquitos of all species used the undersides of the raised huts for resting places during the night (Table XXIX). This suggests another useful surface for "residual" application of insecticide.

(*h*) Rain during the night was followed immediately by increased mosquito activity as shown by higher catches. For instance, on the night of 23/iii/45 when rain fell from 8 p.m. until 11 p.m., the total catch in both huts was 94 at 7 p.m. and 989 at 10 p.m. On the night of 11/iv/45 rain fell from 9·30 until 11·30 p.m. The catch at 7 p.m. was 65 and at 10 p.m. 963.

A very strong breeze, or a very bright moon even on a relatively still night, appeared to be associated with decreased mosquito activity.

(*i*) Specimens of all species commonly found entered the DDT-treated hut (No. 1) readily, and attacked readily, at dusk and dawn, and less vigorously, or so it seemed, at other times. It is certain that a proportion of specimens enter and bite before making contact with treated surfaces which is not difficult in a small room with open door and shutters. At periods other than those of maximum entry, however, activity appeared to be more leisurely, and attacks dwindled often to nil over long periods. From this it was assumed that many specimens were making contact with the walls as soon as they entered and were not attacking because of the influence of the DDT.

Often when shutters, door and eaves of the treated (No. 1) hut were open, it seemed that mosquitos were more numerous than the captures indicated (Table XXV). Restlessness was very obvious in the behaviour of large numbers of individual specimens observed on the walls, and in the general body of mosquitos flying, or "blundering" about the room. It has been assumed, therefore, that after contact with treated surfaces many specimens became restless and flew out again. This view is supported by the figures in Table XXV and particularly by the small number of dead or immobilised specimens recovered from the floor. It is seen from Table XXV that captures in No. 1 hut before treatment were considerably larger than in No. 2. If this assumption is not acceptable then it would seem that the treatment must have had some repellent effect which is contrary to all recorded experience.

The point to be emphasized is that large numbers of mosquitos entered the treated hut; but they were not all accounted for by the 2-hourly collections of immobilised specimens on the floor plus living specimens on the walls, nor, of course, was more than a very small percentage of the total entries accounted for by single early morning captures (Tables XXV and XXVI). Presumably they flew out.

Another point of some interest emerges from the figures in Tables XXV-XXVIII. If the apparent reductions in the treated ranges are interpreted in the light of the observations in the special huts, then it would seem that reduction in the number of all species are based upon early morning captures of anything between about one eighth and one twentieth of the total number of mosquitos that entered rooms during the night. And if the proportions of *A. darlingi* to all species given in Table XXVIII may be assumed to apply to mosquitos entering all rooms, then the reduction of this species would appear to be based upon only about half the number that enter huts during the night.

(*j*) Specimens killed by contact with the treated surfaces in Hut 1 included *A. darlingi*, *Mansonia titillans*, *M. fasciolata*, *Aëdomyia squamipennis*, and *Culex fatigans*.

(*k*) specimens taken alive from treated walls of Hut No. 1 were placed in cages, and observed for survival periods. A few specimens of *C. fatigans* and *M. titillans* lived for 14 hours after they were taken. All specimens of *A. darlingi* and the majority of Culicines, however, died in less than 12 hours. For example, of 57 Culicines captured on the night of 27th March only 2 lived more than 12 hours.

(*l*) Reactions of individual specimens of *Mansonia* and *Culex* under the influence of DDT were observed. Actions or postures usually seen were:—

(i) repeated "cleaning" of probosces and front legs;
(ii) restlessness indicated by continual moving from one place to another;
(iii) uncontrolled flight when "taking off" from the wall, almost a falling away from the surface;
(iv) walking sideways or backwards;
(v) standing with one hind leg drooping and one held high in the usual position.

TABLE XXV.

Lusignan—Total captures in observation Huts before and after treatment of Hut 1.

	Number of nights after treatment									
	1	2	3	11	12	15	16	17	18	19
Hut 1—										
After treatment—										
Total	127	76	127	193	298	278	376	666	130	168
No. immobilised on floor strips ...	84	19	54	45	79	37	63	97	25	66
No. alive on walls and ceiling ...	43	57	73	148	219	241	313	569	105	102
Hut 2—										
Without treatment ...	326	152	248	478	301	321	282	1,117	242	842

Total captures on walls and ceiling of Hut 1 before treatment were... 828, 508, 886, 790, 1,347
Corresponding figures for Hut 2... ... ... 342, 413, 589, 421, 930

TABLE XXVI.

Lusignan—Observation Huts.

Early morning hand-captures only.

Time	Total mosquitos	HUT 1 (Treated)		HUT 2 (Untreated)
		Immobilised on floor strips	No. alive on walls	No. mosquitos alive on walls
6—6.20 a.m.	19	9	10	50
6—6.20 a.m.	20	8	12	36
6—6.15 a.m.	22	10	12	26
6—6.15 a.m.	53	41	12	30
6.5—6.20 a.m.	52	47	5	171
6—6.30 a.m.	80	50	30	129

TABLE XXVII.

Lusignan—Observation Huts.

Captures in Hut 1 on 5 nights before treatment (19–24/iii/45).

Time		Total	*A. darlingi*		*C. fatigans*		*Mansonia* sp.		*Aëdomyia squamipennis*		Others
			♂	♀	♂	♀	♂	♀	♂	♀	
7 p.m. ...		677	1	105	20	112	2	429	0	7	+ 1 ♀ *A. albitarsis*
10 p.m. ...		1157	1	158	3	31	2	441	0	8*	+ 1 ♀ *A. albitarsis*
12 ...		817	1	117	6	36	1	647	0	8	+ 1 ♀ *A. albitarsis*
2 a.m. ...		378	1	42	0	62	0	265	0	8	
4 a.m. ...		473	1	42	1	65	1	337	0	24	+ 1 ♀ *A. albitarsis*
5.30 a.m. ...		857	3	85	1	142	10	378	0	25*	*Remainder too badly damaged to identify
Captures in Hut 1 on 10 nights after treatment.											
7 p.m.	D	73	0	16	4	10	1	42			
	A	223	0	3	0	57	0	162	0	1	
10 p.m.	D	137	1	3	0	22	5	106			
	A	664	0	4	17	90	47	457	0	49	
12	D	85	0	5	2	12	3	61	0	2	
	A	158	0	5	1	19	1	131	0	1	
2 a.m.	D	62	0	4	0	9	1	47	0	1	
	A	127	0	2	4	47	0	99	0	2	
4 a.m.	D	54	0	0	1	14	0	39			
	A	181	0	2	4	47	0	123	0	5	
5.30 a.m.	D	158	0	52	2	22	0	81	0	1	
	A	517	4	206	44	104	0	156	0	3	

D—immobilized on floor strips.
A—alive on walls.

TABLE XXVIII.

Captures in Hut 2 on 5 nights before treatment.

Time	Total	*A. darlingi*		*C. fatigans*		*Mansonia* sp.		*Aëdomyia*		Others
		♂	♀	♂	♀	♂	♀	♂	♀	
7 p.m. ...	457	0	41	7	75	1	329	0	4	
10 p.m. ...	710	1	95	1	33	0	163	0	14	+ 403 Culicines unidentified
12 ...	322	0	48	2	35	0	228	0	7	+ 2 ♀ *A. albitarsis*
2 a.m. ...	221	0	36	1	28	0	145	0	11	
4 a.m. ...	332	0	36	2	90	0	184	0	19	+ 1 ♀ *A. albitarsis*
5.30 a.m.	653	0	170	6	171	9	274	0	23	
Captures in Hut 2 on 10 nights after treatment of Hut 1.										
7 p.m. ...	595	0	41	34	141	5	361	0	11	+ 1 ♀ *A. albitarsis*
10 p.m. ...	946	0	68	19	98	8	708	1	44	
12 ...	819	0	29	10	138	36	586	0	19	+ 1 ♀ *A. albitarsis*
2 a.m. ...	471	0	18	9	40	1	385	0	17	+ 1 ♀ *A. aquasalis*
4 a.m. ...	457	1	24	5	52	3	332	0	40	
5.30 a.m.	1,020	2	220	59	178	0	509	0	51	+ 1 ♀ *A. aquasalis*

TABLE XXIX.

Lusignan—Mosquitos captured under Huts.

Date	Time	Total	*A. darlingi*		*C. fatigans*		*Mansonia*		*Aëdomyia*		—
			♂	♀	♂	♀	♂	♀	♂	♀	
March, 1945 22nd	9 p.m. under hut 1	357	0	53*	0	77	0	225	0	2	*52 unfed
23rd	7.30 p.m. under hut 1	88‡	0	33	1	2	0	46	0	6	
	7.30 p.m. under hut 2	96	0	26†	0	3	0	62*	0	5	*59 unfed
	1 p.m. under hut 1	86	0	32†	0	17	0	32	0	5	†all unfed
	11 p.m. under hut 2	57‡	0	12		45					

‡ not examined for hunger stage.

Anopheles aquasalis (= tarsimaculatus).

This species was recorded only on a few occasions amongst the adult captures in houses, though with *A. albitarsis* and *A. triannulatus* it was frequently found in the larval surveys.

According to Dr. Giglioli's observations over many years it is unlike *A. darlingi*. In most areas it is seasonal in occurrence with peak periods coinciding with the seasons of highest rainfall. Adults feed mostly on cattle and donkeys and they have not been found in houses in any appreciable numbers, by the methods of sampling adopted. It has, therefore, been assumed that this species plays little, if any, part in the transmission of malaria in British Guiana.

In Trinidad, however, according to Shannon and Gillette of the Malaria Research Department, *A. aquasalis* is responsible for most of the malaria. They record that large numbers of adults enter houses nightly, take their meal and leave at dawn. Failure to capture adults of this species in houses in numbers bearing some relation to its occurrence as larvae prompted the initiation of observations with animal bait.

With the co-operation of the Veterinary Stock Officers at the Government Stock Farm two small pens occupied nightly by a donkey and a cow were fitted up as traps, with muslin curtains that could be dropped over doorways. On two mornings the animals were taken out before dawn and the door curtains were dropped. Captures were made in the pens at 6 a.m. with results as shown in Table XXX.

TABLE XXX.

	No of captures	*A. darlingi*	*A aquasalis*	*A. albitarsis*
Vet. Stock Farm	2	1	71	5
Shannon Dawn trap at Lusignan ...	8	4	99	4

A second effort was initiated at Lusignan where a "Dawn" Trap, as designed and used with great success by Shannon, was set up a hundred yards or so west of the observation huts. This trap consists essentially of a darkened wooden chamber large enough for a donkey or cow with a daylight trap at one end. Mosquitos enter the baited chamber through open eaves, take their meal, rest until daybreak and then fly into the trap.

A large calf was used as bait and the captures of Anophelines were small (Table XXX) but they may have been influenced by the rather strong smell of paint with which the trap was treated. With the weathering of the paint and the approach of the wet season, bigger numbers might be expected and observation could be extended.

A. aquasalis adults were apparently active, but they were not entering houses at Lusignan.

Anopheles darlingi in Vegetation.

An experiment was designed to determine how long DDT solution, applied to vegetation, remained toxic to *A. darlingi*. It was never carried out, but the observations made during the preliminary stage are of interest.

A large metal gauze cage ($6' \times 12' \times 7'$) was placed over low shrub and grass in the Botanic Gardens. Known numbers of laboratory bred and fed *A. darlingi* were released in it and attempts were then made to ascertain what percentage could be recovered. Vegetation was disturbed, agitated, shaken violently, and beaten with sticks, with poor results. A careful search disclosed specimens resting, apparently unperturbed, on dead leaves and other débris on the ground at the base of the vegetation. None were found *on* the vegetation. It was apparently impossible to move *A. darlingi* from their harbourages on the ground *beneath* vegetation during the day but there was great activity at dusk. All specimens that had survived this rough treatment flew up, within about five minutes, to the roof of the cage and occupied themselves in vigorous attempts to escape.

Four such observations were made. They may indicate that the spraying of vegetation by day for the destruction of this species would not meet with the success that one might expect unless the spray is directed beneath the vegetation to the ground.

Summary.

1. Simple trials of the effect on mosquitos of single applications of DDT to the internal surfaces of houses were initiated in British Guiana during the period 27th January to 20th April, 1945.

2. The solution used in the first two trials was 4·6 per cent. DDT (72 per cent. para para) in kerosene applied at the rate of about 2 quarts per 1,000 square feet (*i.e.*, approximately 100 mg. of crude DDT per square foot).

3. An apparent reduction in the house population of *Anopheles darlingi*, the chief malaria vector, followed the treatment. Reduction exceeded 99·7 per cent. over eight weeks in the treated houses on one estate and 98·8 per cent. over six weeks on another.

4. In a third trial with a small variety of simple formulations, promising results were obtained with a 6 per cent. emulsion and a $2\frac{1}{2}$ per cent. solution. But mosquito catches over a short period suggest that mud walls, thatch and whitewash may interfere to some extent with the action of DDT.

5. The cost of applications was of the order of one shilling and sixpence for each room (or small hut) of about 1,000 sq. feet internal wall and ceiling surface. This estimate does not include European supervision or the initial cost and depreciation of apparatus.

6. In a trial of the Hochberg-LaMer generator, kills of captive larvae and adults of *A. darlingi* were recorded over a range of about 8,000 feet from the generator, and a considerable reduction of mosquito adults, mostly *C. fatigans*, occurred in bedrooms in the village through which the insecticide "fog" drifted.

7. Initial studies were made of mosquito entry into, and behaviour in, a specially built hut treated with 5 per cent. DDT in kerosene. Mosquitos entered readily. During peak periods of entry, at dusk and dawn, they attacked freely, but at other times, not so frequently as they did in an untreated hut. It is assumed that specimens attacking were mostly, if not all, those that had not made contact with treated surfaces. It was observed that specimens that had made such contacts soon became affected and many of these apparently made their escape through open doors or windows. All specimens taken from the treated walls of the hut died within 14 hours.

8. It was observed in a field cage that in vegetation *A. darlingi* adults harboured on or very close to the ground and could be persuaded to leave this position only with the greatest amount of disturbance.

9. Equipment used in these trials is not considered suitable for "residual" applications.

Conclusion.

It may be well to emphasise again that the trials here recorded are only in their early stages. A long series of observations must be made before definite conclusions can be drawn as to the real effect of the applications.

These and other experiences, however, suggest one obvious conclusion—that a very great deal of research must be conducted if DDT is to be applied intelligently, effectively and economically.

Acknowledgements.

We wish to record our very great appreciation of the help given us by Dr. Giglioli who devoted his extensive knowledge of mosquito and malaria conditions, his time and effort and those of his staff, to our experiments.

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AN ACCOUNT OF A BLACK APHID, *DORALIS FABAE* (SCOP.) SUBSP. *ARMATA* (HAUSMANN)*, FOUND ON *DIGITALIS PURPUREA*, L.

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Introduction.

At the end of June, 1942, large colonies of a black aphid, indistinguishable from *Doralis fabae* (Scop.), were found on foxgloves growing on a hillside in Westmorland. This aphid was found commonly in the mountainous districts of Westmorland and Cumberland in 1943, Caernarvonshire in 1945, and Anglesey in 1946. Observations to be described below have indicated that in nature, this aphid spends the whole of its life on foxgloves, and experiments have shown that it does not readily feed upon the economically important host plants of *D. fabae*.

Whether to give this aphid specific or sub-specific rank is at present a moot point. The extensive works of Börner (1921), Börner & Janisch (1922), Janisch (1926), Franssen (1927 and 1930), and others, which have been recently summarised by Jacob (1945), indicate the ease with which *D. fabae* can be split up into a number of species. The writer's experience of the collection and study of black aphids, and recent discussions with Drs. D. Hille Ris Lambers, I. Thomas and D. Price Jones have all tended to strengthen the opinion that the available evidence suggests that *D. fabae* is not a stable species. Whether this instability is the result of genetic or other causes is not known and must clearly await much more extensive experimental and cytological research, but the writer would venture the suggestion that this group of aphids may be particularly liable to small mutations, especially where host selection is concerned. The outstanding difficulty in this respect is the annual appearance of sexuales, making investigation by means of crossing experiments a piece of long term research; a difficulty that might be overcome by accelerating the life cycle experimentally.

Field evidence that there are geographical variations affecting both choice of host plant and morphological characters is accumulating; there is also evidence that the choice of host plant may be the result of the existence of biological strains. Two examples may be given briefly. (1) In the Snowdonian mountains a black aphid occurs commonly on the thistle *Cirsium palustre* (L.) Hoffm., which can be distinguished from *D. fabae* in a number of morphological characters, but which appears to migrate to *Euonymus europaeus*, L. However, there are many characters in common with the form of *D. fabae* occurring on *Vicia faba*, which is here regarded as the typical form. It is suggested that this Snowdonian aphid may be a geographical race of *D. fabae* which has evolved in the comparative isolation of a mountainous district. (2) This is an example already cited by Jacob (1945). It involves only the evidence, frequently found in the field, that when such a typical host plant as *V. faba* or sugar beet is colonised, other hosts, such as *Cirsium arvense* (L.) Scop., are not: the converse has often been noticed. This evidence clearly points to the existence of some inherent character governing host selection.

It is conceivable that a combination of three factors, *i.e.*, the apparent instability of *D. fabae*, inherent characters governing host selection, and evolution in geographical isolation, may have led to the existence of a number of sub-species. When these sub-species can be granted specific rank depends fundamentally upon the judgment of the observer. In the case of the foxglove aphid, while the biological and experimental evidence would appear to warrant specific rank, the

* Since submitting this paper, the writer has had reason to change his views regarding the use of *Doralis* Leach, and now considers that it is desirable to continue to use *Aphis* L.

morphological evidence is so slight that it has been decided to place this aphid as a sub-species of *D. fabae*, Scop., a decision which may have to be modified in the light of future experience.

Hausmann (1802) described the apterous and alate viviparous females of a black aphid which he found on foxgloves at the end of June, 1801: he named it *Aphis armata*. Kaltenbach (1843), Theobald (1912, 1927, 1929), and Janisch (1926) refer to this species as a synonym of *A. papaveris*, F., *A. rumicis*, L., and *A. fabae*, Scop., respectively. *A. fabae* is placed in the genus *Doralis* Leach by Börner & Schilder (1932), so that, the foxglove aphid now becomes *Doralis fabae* (Scop.) subsp. *armata* (Hausmann).

Biology.

The observations of one complete cycle are summarised below. Colonies of apterous viviparous females and larvae were found on foxgloves, in Cumberland on 30th May, 1943. At this time migrants of *D. fabae* were just beginning to develop on *Euonymus europaeus*, L., some five miles away. However, the size of the foxglove colonies ruled out any possibility of their having been derived from *E. europaeus*. (In this connection it may be noted that parallel observations of *D. fabae* colonies were being made.) In addition, colonies could not be found on any of the usual summer hosts of *D. fabae* growing in the immediate vicinity of the infested foxgloves. From 21st-24th June many colonies were found in Westmorland and Cumberland, extending throughout the altitude range of the host plant. At this time alate viviparous females were present mainly on slopes facing south, and were migrating. On 22nd June many newly founded colonies appeared on foxgloves on the south side of the Kirkstone Pass. At the same time numerous thistles (*Cirsium arvense* (L.) Scop.) and *C. palustre* (L.) Scop. and docks (mainly *Rumex obtusifolius*, L.) were examined alongside the foxgloves, but only a single alate viviparous female and 8 to 10 larvae were found on the docks (*see* below). These colonies were examined at approximately monthly intervals. Sexual forms and eggs were found on 27th and 28th September and oviparous females could still be found in mid November. The first hatching was noted on 7th and 9th April, 1944, whilst on *E. europaeus* it had occurred on 14th March. In laboratory cultures the fundatrices took about three weeks to mature; their progeny contained no alatae, and only a proportion of alatae were found in the second and third generations. It would appear that there is no completely winged generation. Observations made in North Wales during 1943 and 1945 support those made in the Lake District.

In most cases eggs have been found on rather small plants growing in comparatively exposed situations, *e.g.*, on top of a bank, and not too closely surrounded by other vegetation. It seems usual to find a few plants bearing very numerous eggs (*e.g.*, 541 on 5 leaves), and most plants with one or two or none: *i.e.*, at stations where the aphid is known to occur. These eggs are laid all over the upper and lower surfaces of the leaves, and are viable irrespective of position. During the course of these observations foxgloves have been very heavily infested by the Capsid, *Dicyphus pallidicornis*, F., which may have driven the aphids to less succulent plants.

The newly hatched larvae tend to feed near the leaf base, and the adult fundatrices upon the young leaves in the centre of the plant. As the plant grows the colonies are formed on the flowering spike. The earliest formed alatae fly to both new flower spikes and to young rosettes. After flowering the aphids are found under the leaves and on the crowns of plants which will flower in the following season. Throughout the season the size of apterous viviparous females appears to be closely correlated with the state of freshness of the host, so that care should be taken in the use of measurements for taxonomic purposes. The sexuales are the progeny of apterous sexuparae, and the males are winged.

Throughout its life this aphid is attended by numerous ants which, when the colonies are on rosettes, heap soil and débris over them. The following species of ants have been recorded:—*Formica fusca*, L., *Acanthomyops flavus* (F.), *A. niger* (L.), *Myrmica ruginodis*, Nyl. and *M. laevinodis*, Nyl.

As regards predators, Syrphids were frequently found, but the species were not recorded: Cecidomyiid larvae were numerous in 1945, as were Thrombid mites.

The colonies at one station were wiped out by the Braconid, *Aphidius* (*Lysiphlebus*) *dissolutus*, Nees, which has been kindly identified by Mr. G. E. J. Nixon of the Imperial Institute of Entomology.

Experimental Work.

Numerous unsuccessful attempts were made to transfer this aphid to beans (*Vicia faba*, L.) and thistles (*C. arvense* (L.) Scop.). Successful transferences were made to *Rumex crispus*, L., and *Rumex obtusifolius*, L. However, Jacob (1945) has pointed out that these plants are readily accepted by a number of black aphids, and are not, therefore, suitable for this type of investigation. The search for really specific host plants is of the utmost importance to the study of the " black aphids ". In the winter of 1943 numerous eggs were transferred to potted *E. europaeus*, many of them hatched, but only a single fundatrix survived and reproduced. Five of its progeny matured on spindle and were transferred to beans (3) and foxgloves (2); the former died, the latter thrived.

For many reasons, such as lack of facilities and humidity of plants kept under lamp glasses, this type of work is unsatisfactory. Consequently, the type of experiment carried out by Jones (1942) was undertaken. This is referred to as a colonisation experiment, because the aphids are given freedom to choose their hosts.

A circular muslin cage 6 ft. in diameter by 2 ft. 6 in. high was erected on a bare patch of ground at Cambridge on 19th May, 1944. A potted foxglove bearing a thriving colony of *D. f. armata* was sunk in the centre, and around it were planted: 3 bean plants, 3 sugar beet seed plants, 4 *C. arvense*, 2 *R. obtusifolius*, 2 *R. crispus* and 4 foxgloves. One of the thistles was growing in the ground before the cage was erected (4, Table I). The plants were as nearly as possible evenly dispersed in the space available. The results are recorded in Table I, and show a very marked contrast as between beans, beet and thistles on the one hand, and docks and foxgloves on the other.

It will be noted that all the foxgloves were colonised within five days, and all the docks within seven days. The thistle (4) almost certainly became colonised as a result of the top of the cage being blown off on the night of 21/22nd May and the alatae were much larger than any produced on the foxglove. Otherwise, only casual records were made on beans and beet, and none on thistles. During the course of this experiment *D. fabae* was very numerous on plants growing near the cage, and it is thought that the eventual colonisation of beans and beet was certainly due to contamination, when the top of the cage was removed for inspection.

A further series of experiments was set up using smaller cages, but the number of aphids introduced was generally too large, and the cages became too overcrowded to give a fair result. In addition evidence was obtained that the thistle black aphid was distinct from the bean race, so that the results became unnecessarily complicated. As thistle colonies were used as controls, the whole series is omitted.

TABLE I.

Summary of data of colonisation experiment.
Colonisation of host plants of *D. f. armata.*

Host Plant	Plant Number	Number of days										
		1	3	5	7	10	12	15	17	23	27	38
Bean	1	o	o	o	o	o	o	o	o	†	†	o
	2	o	o	o	o	o	o	o	o	o	o	o
	3	o	o	o	o	o	o	o	o	†	‡	‡
Sugar Beet	1	o	o	A	o	o	o	A	o	o	A	‡
	2	o	o	o	o	o	o	o	A	o	o	o
	3	o	o	o	o	o	o	o	o	o	o	o
Cirsium arvense	1	o	o	o	o	o	o	o	o	o	o	o
	2	o	o	o	o	o	o	o	o	o	–	–
	3	o	o	o	o	o	o	o	o	o	o	o
	4	o	A	‡	‡	—	—	—	Removed	—	—	—
Rumex obtusifolius	1	o	o	o	‡	‡	‡	‡	‡	‡	‡	‡
	2	o	o	o	‡	‡	‡	‡	‡	‡	‡	‡
Rumex crispus	1	o	o	A	‡	‡	‡	‡	‡	‡	‡	‡
	2	o	o	o	‡	‡	‡	‡	‡	‡	‡	‡
Digitalis purpurea	1	A	‡	‡	§	§	§	§	§	§	§	§
	2	o	‡	‡	§	§	§	§	§	§	§	§
	3	o	‡	‡	§	§	§	§	§	§	§	§
	4	o	‡	‡	§	§	§	§	§	§	§	§

A = Alatae present.
† = A few aphids feeding.
‡ = Well established colonies.
§ = Aphids too numerous to count.

From the biological and experimental evidence the following features are regarded as distinguishing *D. f. armata* from *D. fabae*.

1. *D. f. armata* can spend the whole of its life on foxgloves.
2. The sexuales of *D. f. armata* are produced by apterous sexuparae.
3. There is a difference in the hatching dates, and there is no mass production of migrants as in *D. fabae*.
4. *D. f. armata* does not transfer to the typical summer hosts of *D. fabae*, beans and beet, and does not take to them when given the opportunity.

Morphology.

Janisch (1926) and Franssen (1930) gave detailed descriptions of the morphology of the black aphids, which are applicable to *D. f. armata* in all its most important features. Within this group it is very difficult to separate *D. f. armata* from *D. fabae*, and *D. viburni*, Scop., because each species shows a considerable amount of variation in measurable characters. In *D. f. armata* the age and condition of the host plant has a very pronounced effect upon the size of body and appendages:

the same thing occurs in *D. fabae* but is further complicated by the fact that what is generally regarded as *D. fabae* undoubtedly contains two or more distinct strains. There are so few differences and so much overlap that detailed descriptions of *D. f. armata* have been found to apply equally well to specimens of *D. fabae*, and therefore, are not included in the present account. In order to limit as far as possible the sources of variation in *D. fabae* material, comparisons have only been made with specimens derived from beans and spindle trees.

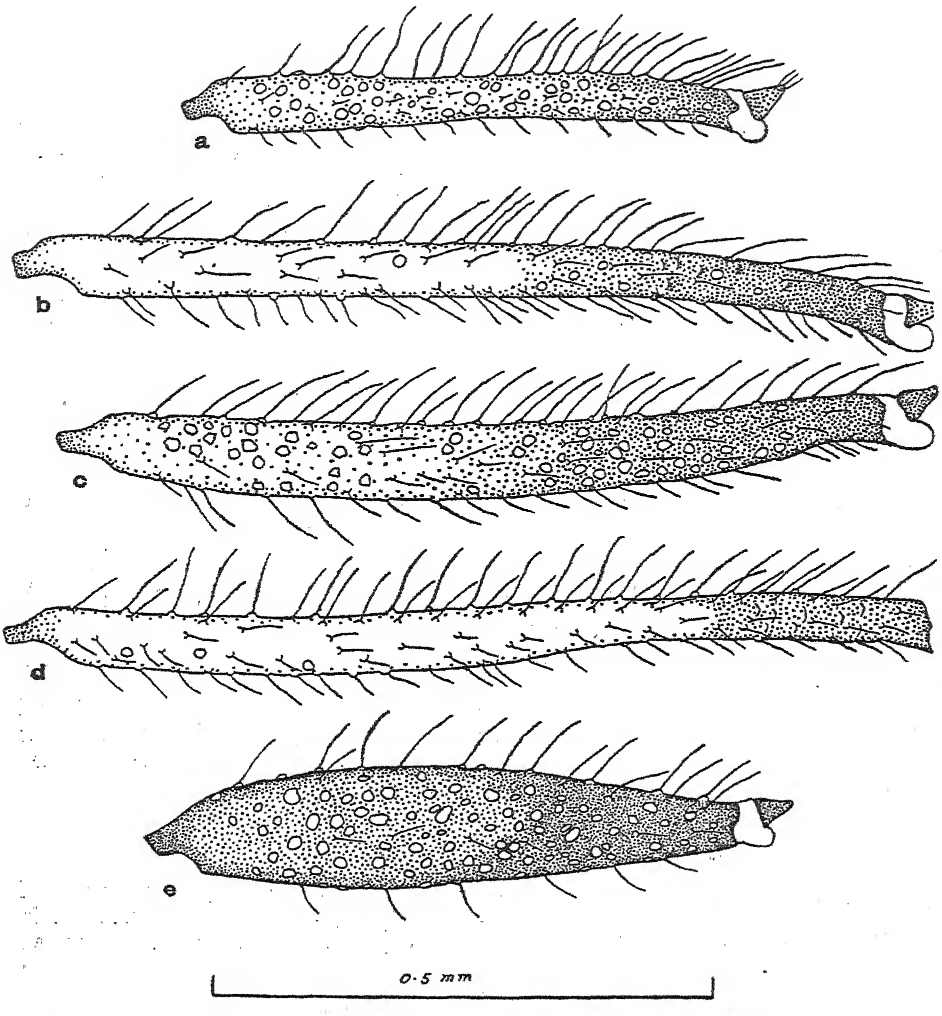

FIG. 1.—Hind tibiae of oviparous females:—(a) *D. f. armata*, Hausm.; (b & c) *D. cognatella*, M. G. Jones; (d) *D. rumicis*, L.; (e) *D. fabae*, Scop.

The following are the main points of difference which have been noticed.

(1) In *D. f. armata* there are rarely more than two long hairs in the anterior group on the sub-genital plate: in *D. fabae* there are frequently four to six. This holds for alate and apterous viviparous females.

(2) In *D. f. armata* the hind tibiae of the oviparous females are not swollen; they are considerably swollen in *D. fabae*. This is the most outstanding morphological difference which has been observed. In fig. 1 a typical hind tibia of *D. f. armata* is compared with those of *D. fabae*, *D. rumicis*, L., and *D. cognatella*, Jones.

Table II gives measurements of single specimens of each phase of *D. f. armata*.

TABLE II.

Measurements in millimeters of body length and appendages on the right hand side, of single specimens of *D. f. armata*.

	Body excluding cauda	Antennal segments				Hind tibia	Cornicle	Cauda
		III	IV	V	VI			
Fundatrix	2·24	0·425	0·182	0·133 + 0·199		0·896	0·199	0·199
Apt. v. ♀ ... ... (progeny of Fundatrix)	2·208	0·365	0·265	0·199	0·116 + 0·365	1·079	0·315	0·232
Apt. v. ♀ ... ... (at flowering time)	2·739	0·481	0·365	0·265	0·116 + 0·382	1·295	0·398	0·249
Al. v. ♀ (June)	2·390	0·415	0·332	0·286	0·149 + 0·415	1·295	0·249	0·199
Secondary sensoria ...		13	0	0				
Ovip. ♀	1·643	0·232	0·182	0·149	0·116 + +0·299	0·730	0·182	0·166
Al. ♂	1·776	0·365	0·286	0·215	0·116 +0·382	0·963	0·116	0·116
Secondary sensoria ...		32	22	14				

A single freak was found in which there were secondary sensoria on antennal segment III, a single malformed wing, a divided genital plate as in the oviparous female, and no sensoria on the hind tibia (one hind tibia missing). The specimen contained a body which appeared to be an egg.

Acknowledgements.

The writer wishes to express his appreciation of the helpful criticism of Drs. I. Thomas, D. Hille Ris Lambers and D. Price Jones, already referred to in the text. Thanks are also due to Mr. G. E. J. Nixon who kindly identified samples of parasites.

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STUDIES ON WHEAT BULB FLY, *LEPTOHYLEMYIA COARCTATA*, FALL.

II. Numbers in relation to crop damage.

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Quantitative Observations on Damage in the Field.

Development of an Attack at South Duffield in 1944.

A 12-acre field which had been cropped with potatoes in 1943 was selected for study; by a fortunate chance it was heavily infested but in spite of this it ultimately made a satisfactory crop. Certain details of the field have already been described in an account of the biology of the fly (Gough, 1946). The potatoes were main crop and the haulms had covered the ground well during the growing season. The yield was good and the tops were still green when the crop was lifted at the end of September and early October. After the second harrowing, wheat, mostly Little Joss, was drop-drilled and ploughed in about 2-inches deep at 15-stone per acre. A few acres of Standard Red were sown at one end.

The observations varied according to circumstances but attempts were made to secure some or all of the following information at regular intervals.

1. A plant count based on twenty 2-foot squares taken at random over the field. The seed rate was very heavy and distinguishing between plants was difficult even in the early part of the year.
2. A count of larvae based on the numbers of damaged shoots containing larvae in the same 2-ft. squares. Usually all damaged plants were brought into the laboratory for examination.
3. An estimate of the percentage of plants and shoots attacked by taking twenty (or occasionally ten) plants at random from twenty different sites. This was not normally necessary when a complete plant count was made but it was often done because in the early stages some plants might be infested with larvae without showing symptoms.

A damaged shoot was counted as long as it was still recognisable and attached to the plant. Because sometimes shoot counts were made in the field, only tillers which had emerged from the sheath were counted, although occasionally unexposed tillers were infested. Larvae in such tillers were recorded.

From the material brought back, information was obtained on instar, size, amount of feeding and numbers of shoots from healthy and attacked plants. Finally, when the larvae were leaving the plants to pupate in the soil, twenty sites 6×12 inches in area were excavated to a depth of about $1\frac{1}{2}$ inches and the numbers of larvae and puparia in the soil estimated. The results are shown graphically in fig. 1, and numerically, with their standard errors, in Table I.

The number of larvae found and the percentage of plants attacked increased from the date of the first examination on 26th January to some date between 10th and 23rd March. This gradual increase is due to variation in the time of hatching of the eggs, in the time taken by larvae to infest plants, and in the time taken by the plant to develop typical symptoms. The two larval counts of 23rd March and 4th April of 586,000 per acre and 584,000 per acre, both with an error of about 8 per cent., agree so closely that it seems reasonable to accept the figure as the maximum number of larvae which successfully infested plants. There was an unknown mortality of eggs and of larvae before they reached a plant, but once this had occurred they appeared to run little risk until they had to leave the plant

TABLE I.

Data from South Duffield (1944).

Date	Plants per acre	Total damaged shoots/acre	Larvae or puparia per acre	% Damaged plants	% Damaged shoots	Mean No. of shoots per plant
26th Jan.	1,554,548 ± 7·23%	approx. 1600	approx. 1,600	0·1	—	between 1 and 2
14th Feb.	1,420,056 ± 4·09%	138,303 ± 11·8%	138,303 ± 11·8%	9·70 ± 1·268	4	2·24
1st March	—	—	—	37	—	2·75
10th March ...	1,320,957 ± 5·2%	582,615	542,322 ± 7·5%	36·89 ± 2·712	approx. 4·7	3·03 ± 0·0629*
23rd March ...	—	732,897 ± 8·4%	586,320	44·5 ± 5·04	18·11 ± 2·91	3·76 ± 0·2355
4th April	1,692,306 ± 5·68%	1,085,733±7·2%	583,704 ± 8·3%	46·55 ± 3·493	—	3·81
17th April	—	—	—	30·4 ± 3·495	12·95 ± 0·7728	3·68 ± 0·1205
27th April	—	—	187,358 ± 28% (puparia)	38·75 ± 4·595	15·95 ± 1·623	3·49 ± 0·1255
2nd May	—	—	174,240 ± 28·7% (puparia)	36·5 ± 3·307	14·85 ± 1·392	3·09 ± 0·1858

* Damaged plants only.

for another. The proportion of larvae found dead in the shoots was very low and there was no evidence of whole shoots or plants being taken by birds or other organisms.

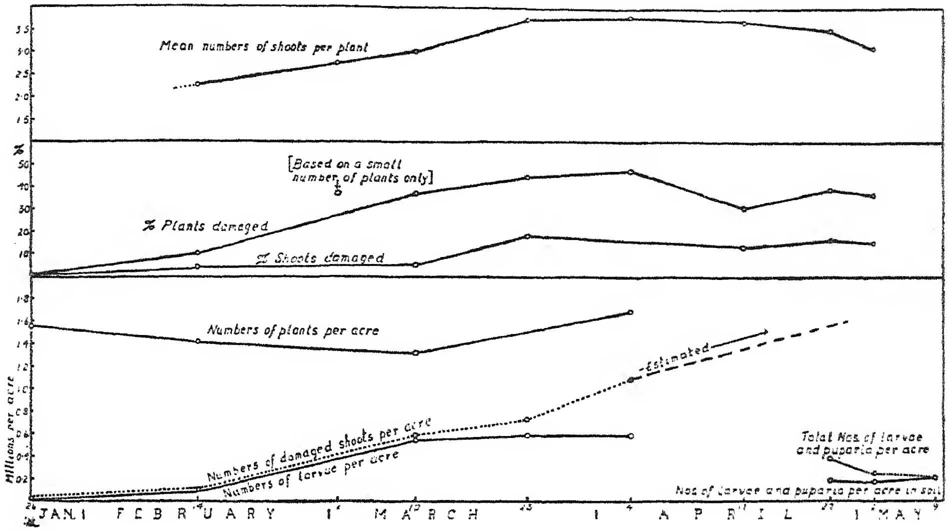

FIG. 1.—Fie observations at South Duffield.

In the early stages the larva usually migrates from one shoot of the plant to another and may spend all its life in one plant if there are sufficient shoots. From the beginning of April the plants were too thick to make total counts and it was not possible to make a satisfactory estimate of the number of individuals again until the larvae were entering the soil for pupation. In view of the smaller sampling unit (which was chosen to avoid spending too much time on soil examination) the sampling errors are much greater. Three counts of larvae and pupae in the soil were made with the following results:—

27th April	$187{,}308 \pm 28$	per cent. per acre.
2nd May	$174{,}240 \pm 28 \cdot 7$	per cent. per acre.
9th May	$209{,}088 \pm 17$	per cent. per acre.

On the first two occasions a certain number of larvae were still in the plants and this was estimated roughly as about 180,000 per acre on 27th April and about 55,000 per acre on 2nd May. Despite the admittedly great errors it would seem that an appreciable drop in numbers had occurred during April and it seems likely that this was due to losses through birds or other predators or exposure to dry conditions during larval migration.

The earlier plant counts falling from 1·5 millions per acre in January to 1·3 millions in March agree well. A decrease in the number of plants early in the season often occurs through various causes, and was noted in the precision wheat sampling observations (Anon., 1933-38). For the final plant count in April it was decided to remove all the plants from twenty sites 2×1 feet in area as it was impossible to distinguish between separate plants in the field at that stage. This gave the very high figure of 1·7 million plants per acre and if this is extrapolated on a curve parallel to that of the earlier counts it suggests an original establishment of over 2 million plants per acre. The difference between the counts of 10th March and 4th April is undoubtedly significant and as the later count must be presumed to be more accurate it seems that in earlier counts close plants must have been grouped as one.

The percentage of plants attacked reaches a maximum of about 45, remains stationary for a period and then falls off slightly. This is probably due to a number of attacked plants dying and disappearing completely. The sudden drop on 17th April is attributed to the rolling and harrowing about that time which may have removed damaged shoots containing larvae which were not able to infest new plants immediately. The difference between the figures for the two dates is just about significant. By 27th April the figure had risen again to about 40 per cent. More important, however, is the percentage of shoots damaged. This rises to a maximum of about 18 per cent. and then falls off slightly with a similar drop on 17th April.

Reference to the graph showing the number of damaged shoots and numbers of larvae per acre, reveals that these agree closely up to 10th March and then the number of damaged shoots increases rapidly while the number of larvae remains constant. This is the stage at which the grubs have killed one shoot and entered another. While this is happening, however, the mean number of shoots per plant has increased from 3·03 to 3·81, so that the percentage of shoots attacked does not rise. The amount of feeding from this date could not be estimated accurately but the number of shoots per plant falls again to 3·09 on 2nd May, which represents a loss of perhaps one million shoots per acre. These represent the shoots damaged earlier (and the similarity of the figures suggests up to 4th April), which have since died and disappeared. This number may include some shoots which would be dying normally, though according to figures published by Russell and Watson (1940) it seems unlikely that the natural decrease would be very great at this stage. About 15 per cent. of the total number of shoots are, however, still damaged and these are mainly shoots attacked since 4th April or about that date. Assuming a plant population of 1½ million per acre, this 15 per cent. represents very approximately 700,000 further shoots destroyed. It seems well established that on an average each larva accounted for two shoots up to 4th April. Between then and pupation the population dropped considerably. If this decrease occurred early, each remaining larva must have destroyed a further 3·5 shoots; if the decrease occurred after feeding ceased, each larva would have only destroyed a further 1·2 shoots. It seems reasonable to suggest that the total number of shoots destroyed by each larva that reached the pupation stage was about 4 and this would agree with laboratory observations.

There appear then to have been two reasons for the success of the crop; one was the high initial number of plants and the other was that early sowing resulted in early tillering. These two factors combined to give a very high number of shoots per acre.

Details of other Fields in 1944 *and* 1945.

It was not possible to visit other places as frequently as South Duffield but an attempt was made to secure the same type of information on at least one occasion. Three farms at Goole Fields, Stokesley and Selby Common were visited because crop damage was reported there and two farms at Yokefleet and West Hardwick because serious damage had occurred there in previous years after fallows. As in these two farms, no wheat was taken after a fallow in 1943-44, wheat fields after potatoes were selected for observation and only slight infestations developed. The numerical data for all these fields are summarised in Table II.

In 1945 particular attention was paid to the maximum number of larvae occurring in fields on which egg counts had been made in 1944. Puparia counts were also made where possible. The results are given in Table III with a note on the condition of the crop in late April. With the exception of the field at Stokesley all the corn was sown late and went in badly when the land was wet. There was also a greater or lesser amount of damage by standing water on all fields and the

TABLE II.

Numerical Data of Attacks in various Localities—1944.

District and Soil	Acreage	Variety	Prev. crop	Time and rate of sowing		Larvae/ac.
Goole Fields‡ ... (Medium warp)	(a) 3 ac. †	Bersée	Potatoes	Nov.	—	573,903 ± 10·1% (30th March)
Goole Fields ... (Medium warp)	(b) 3 ac. †	Holdfast	Potatoes	Nov.	—	316,000 ± 12·5% (30th March)
Goole Fields ... (Medium warp)	(c) 9 ac.	Holdfast	Potatoes	Nov.	—	400,000 ± 13·5% (30th March)
Stokesley ... (Clay)	8½ ac. †	Steel	Fallow	Sept.	9 st.	253,737 ± 16% (24th April)
Selby Common... (Sand)	2 ac. †	Little Joss	Potatoes	Nov.	15 st.	180,474 ± 7·2% (13th April)
Yokefleet ... (Heavy warp)	11 ac.	Redman	Potatoes	Oct.	14 st.	20,146 ± 19·3% (14th April)
W. Hardwick ... (Clay)	16 ac.	?	Potatoes	—	—	22,324 ± 23% (18th April)
S. Duffield ... (Sand)	12 ac.	Little Joss	Potatoes	Oct.	15 st.	583,704 ± 8·3% (4th April)

District and Soil	% plants attacked	% shoots attacked	Shoots/plant*	Puparia/ac.	Crop Result
Goole Fields‡ ... (Medium warp)	78·7±3·93	50·72±5·234	2·08±0·157 1·64±0·00023	—	Failed
Goole Fields ... (Medium warp)	19·0±2·667	15·5	1·72±0·119	—	Satisfactory
Goole Fields ... (Medium warp)	38·5±3·804	16·7 ±2·404	3·424±0·145 3·203±0·236	344,124±9·8% (11th May)	Good
Stokesley ... (Clay)	66·0±4·27	63·3 ±10·2	6·827±0·3512	—	Good
Selby Common... (Sand)	80·65±2·82	58·65±4·109	2·2	196,020±27·7% (10th May)	Failed
Yokefleet ... (Heavy warp)	9·0	2·4	4·35	39,204 (12th May)	Good
W. Hardwick ... (Clay)	6·0	3·4	2·36	17,424 (10th May)	Good
S. Duffield ... (Sand) ...	44·5±5·04	18·11±2·91	3·76±0·2355	209,088±17% (9th May)	Good

† Fields examined because they were poor or failing.
* Where two figures are given the first is for healthy plants and the second for attacked plants.
‡ All three flats a, b, c, adjoined and the potatoes were lifted at the same time and the wheat was sown at the same time.

TABLE III.

Numbers of Eggs, Larvae and Puparia in 1,000's/ac. (1945).

District and Soil	Eggs	Larvae	% attacked plants	% attacked shoots	Puparia	Crop
S. Duffield ... (Sand)	2,225±11·6% (28th Nov.)	483±7·5% (28th Feb.)	41*	29*	283±16·1% (24th Apr.)	Poor
Sunk Island (Clay)	1,925±22·9% (21st Dec.)	373±8·9% (2nd Mar.)	58	44	126±14·5% (24th May)	Poor
Dirtness Bridge 5½-ac.	1,300±16·6%	569±8·1%	51		166±20·2%	V. Poor
11-ac. (Black sand)	1,300±16·8% (14th Nov.)	541±4·5% (12th Mar.)	45		314±13·0% (25th Apr.)	Poor
Stokesley ... (Clay)	550±45·8% (28th Sept.)	140±10·7% (23rd Mar.)	38	11		Good

* Based on means of plots of different cereals.

result was a thin plant with few tillers when the larvae hatched. The numbers of larvae were much the same as in 1944 but naturally their effect was far greater and with the exception of the field at Stokesley all crops were severely thinned by the end of April.

There is a considerable difference between the number of eggs and the number of larvae successfully infesting plants, the reduction being 56 and 58 per cent. at Dirtness Bridge and 75-81 per cent. at the other centres. There is a further variable reduction between the larval stage and pupation of 42-71 per cent. In 1944, however, at four centres the puparia count was similar to the larval count (apparent increases are within the sampling error) but at South Duffield there was a reduction of 64 per cent.

Discussion.

The number of fields examined was too few to enable many generalisations to be made. The maximum number of larvae recorded was about 580,000/ac. at South Duffield in 1944 and a very good crop resulted. All other fields with similar numbers of larvae either failed or were severely thinned. The 300-500,000/ac. group resulted in satisfactory crops in 1944 but poor crops in 1945 for reasons already stated. Under 300,000/ac., all crops were successful with the exception of the flat at Selby Common, which failed with a population of only 180,000. It is possible that this estimate is rather low as it was made on 13th April and there is some evidence that larval populations decreased about this stage. The main reasons for this failure were, however, that the wheat was sown late and even in April the number of shoots per plant was only just over two.

The percentage of plants and shoots attacked in the fields which were poor or failed ranged from 41-81 and 29-59 respectively. In the fields that gave a satisfactory yield the figures were 6-66 per cent. and 2-63 per cent. or, neglecting the field at Stokesley in 1944 in which although there were few plants each had a very large number of shoots, 6-45 per cent. and 2-19 per cent. The number of shoots per plant is evidently of the greatest importance and the value of early sowing (where conditions and circumstances permit) so that tillering is in progress before the attack starts is emphasised. Petherbridge & others (1944, 1945) have also

drawn attention to this. Soil condition as well is likely to influence the rate of growth of the plant and this is the only explanation for the difference between flats (*a*) and (*c*) at Goole Fields in 1944. Admittedly the number of larvae was higher on flat (*a*) but not so much as to lead one to expect a complete failure there and a perfectly healthy crop on flat (*c*). The higher number of shoots per plant on the latter area has evidently been a factor of major importance, the only differences being in variety and soil. Variety is not likely to be concerned as the Holdfast only had 1·72 shoots per plant in area (*b*), which adjoined (*a*). It seems possible that some soil factor had inhibited tillering though the only deficiency which could be discovered by analysis was of potash. To what extent the vigour of the plant (if there is such a positive conception) can be correlated with its rate of growth is discussed in a later section.

Comparison of Numbers of Shoots from attacked and healthy Plants.

Gemmill (1927) pointed out that there was some evidence that attacked plants tiller more readily than healthy ones. This was noticed consistently at South Duffield in 1944; for example, on 14th February the mean number of shoots on healthy plants was $2·19 \pm 0·0884$ and on attacked plants $2·65 \pm 0·133$. The difference is significant. On 4th April the figures were respectively $3·49 \pm 0·1835$ and $4·17 \pm 0·1606$, the difference being just significant. On the other hand at Goole Fields on flat (*c*) the figures were $3·424 \pm 0·145$ and $3·203 \pm 0·236$ and these do not differ significantly. On flat (*a*) the figures were $2·08 \pm 0·157$ and $1·64 \pm ·00023$. Here the damage was extensive and started at a time when the plants had scarcely tillered so that they had no chance to recover.

In 1945 the differences noted were very slight and in all cases the healthy plants had a slightly greater number of shoots. These figures are given in Table IV. As the differences were so slight the standard errors are not given.

TABLE IV.

Numbers of shoots of healthy and attacked plants, 1945.

Date	Place	Variety	Date sown	Healthy	Attacked
21st March ...	Sunk Island	Holdfast	27th Oct.	1·49	1·36
24th March ...	S. Duffield	Giant Rye	Nov.	2·74	2·54
25th March ...	Stokesley	Scandia	Oct.	6·47	5·88

The date of examination, the season and the condition of the plant at the time of infestation are obviously important factors in determining if any stimulation of tillering can result from pest attack, and if so, whether the effect is likely to compensate to any extent for the damage done.

Estimates of Pest Damage to Crops.

Attention in recent years has been directed to accurate estimates of the number of pests per acre causing damage of various degrees to crops. The war time wire-worm survey (Ministry of Agriculture, 1944) is an excellent example of this, but here, as in other cases, though there is a general relationship between population and crop yield when a number of fields are examined, a comparatively high proportion of fields fail to show such a correlation. This is quite understandable as apart from the possibility of an inaccurate estimate of the pest population so many other factors such as soil fertility, soil conditions and season have an important effect. It is impossible to measure all these factors or, if it were, to integrate their effects, but the ultimate result is seen in the rate of growth of the crop. Provided this rate of growth in whatever units are suitable (*e.g.*, leaf area,

number of plants or shoots per unit area) can keep pace with pest damage so that when this is over the total number of units per acre has not fallen below a certain minimum, the crop will be satisfactory. The concept of attaching importance to the vigour of the crop is a very elementary one familiar to farmers and plant pathologists, but it is rarely mentioned in the literature and appears to have received insufficient attention in so far as it can be studied statistically. In the present study the number of shoots per plant at various times gives an illuminating picture of the vigour of the plant with the pest attack superimposed.

It is emphasised that the percentage of the crop attacked at one time is not necessarily of great importance in itself. As has been shown in this paper a relatively high proportion of the crop may be damaged and yet a good yield may result. For an insect which can destroy a shoot (or a comparable unit) without necessarily destroying the whole plant, an estimate of the percentage of the shoots attacked is more likely to be useful than the percentage of plants attacked. When the attack reaches considerable dimensions the total number of units may be decreasing rapidly every day. The writer considers that a study of the rate of this decrease (or in some cases increase) considered in relation to the condition of the crop would yield information of great importance in understanding the reactions of the crop to pest attack. It is not suggested that this paper gives as complete information as is necessary for this type of study but it does indicate a way in which the subject might be investigated. A thorough knowledge of the behaviour of healthy plants under various conditions would be needed to interpret the results of such observations and for wheat a very comprehensive account has been prepared by Russell and Watson (1940).

It is realised that an observant and experienced farmer or plant pathologist can often draw on his experience so that he can consider all the different factors together but some numerical expression of them would be extremely valuable.

Numbers of Eggs laid in different Crops.

The occurrence of damage after certain crops suggests that a comparison of the number of eggs laid in different crops would give useful information. Gemmill (1927) recorded a few such results but they were based on too few samples to have much value. Bremer (1929) and Crüger and Körting (1931) have carried out more detailed studies in Germany and their results are discussed later.

Technique.

Various methods for removing eggs from the soil were tested. The first series of samples was examined by sieving the soil through a 1/10-inch mesh sieve on to a dark surface but this proved laborious and not very accurate. The next method was the separation of the eggs from the soil by flotation in magnesium sulphate solution in a conical flask; the flotsam was tipped into a Buchner funnel lined preferably with black filter paper which was then examined for eggs. This was also tedious, though tests showed that 85-95 per cent. of known numbers of eggs added to soil were recovered. It was used for examining surface samples in 1943 and 1944 but it was necessary to use several flasks for each surface sample and when deep 4-inch cores were examined the numbers of flasks required became unwieldy. For these larger samples it was found convenient to reduce the bulk of soil by washing through a 60-mesh sieve and treating the residue with magnesium sulphate as before. A final improvement necessary with soils containing a large quantity of organic matter was to air dry the filter paper with its débris and sieve this again through a 1/16-inch mesh sieve which allowed the eggs to pass freely. Residues were examined for eggs at all stages. By this method two people could examine 30-40 samples a day with a high degree of accuracy.

The identity of the eggs was at first only based on the following circumstantial evidence:—

(1) The fly was the most abundant species of Diptera present. On 22nd July, 1943, for example, out of 424 flies caught in net sweeps, 156 were wheat bulb fly, 150 were frit fly and 80 were other Anthomyiids. The frit flies were only present for a short period and there was no possibility of confusion with their eggs. The eggs of the other Anthomyiids were examined in dissected females and though similar to *L. coarctata,* could at once be distinguished under the binoculars by slight differences of shape or pattern.

(2) The time at which the eggs appeared in the soil immediately followed the maturation of the ovaries of *L. coarctata* and eggs found in the soil were identical as far as could be seen with eggs in dissected females and eggs laid by females in captivity.

(3) Eggs were not found in soils in districts where wheat bulb fly was not common.

(4) All eggs recovered from the soil were inspected under a binocular microscope and those of which the identity was doubtful were not recorded.

It was not possible to retain all eggs to identify the later stages but all the larvae from some hundreds which hatched out were identical with those of *L. coarctata* and about 30 adult flies were reared.

1943 Results.

The first series of samples, 6 × 8 inches in area and 1 inch deep was taken on 15th July from the following adjacent crops.

Wheat.—A field of 16 acres which had been badly attacked by wheat bulb fly in the spring; the central part had been disced up and the headlands for a distance of 20-30 yards in were left and gave a satisfactory stand and yield.

Oats.—These were sown late on the part of the wheat field which failed. They were badly attacked by frit fly and never became established. The field rapidly filled up with straggling weeds, mainly spurrey (*Spergula arvensis*) and cornflower (*Centaurea cyanus*) and by the time the flies were laying, the land was thickly covered with vegetation.

Roots (8-acres).—This term is loosely used to cover savoys, kale and swedes. They were late and at the time of the first sampling about three quarters of the soil between the rows was still uncovered and even at the end of July the leaves were far from meeting in the rows. The flat was scruffled and hoed two or three times during the month of July.

Potatoes (8-acres).—These were Majestics and were hardly meeting in the rows when oviposition began in early July, but they filled up rapidly.

Twenty samples were taken at random over each flat, cutting across the roots of plants if necessary. In the potatoes twenty samples were taken in the tops of the ridges which in this district are very broad, and twenty on the sides and bottoms of the ridges and the numbers of eggs per unit of horizontal area calculated.

In view of the inaccuracy of the dry examination of the first sampling no statistical analysis was made but the figures are in the same relative order as those of the wet examination of the final sampling. They certainly showed that large numbers of eggs had been laid by the middle of July. The flies had largely disappeared by the end of July and a final sampling was made on 10th August. The area of the sampling unit was reduced to 6 × 4 inches. The numbers of eggs in the samples ranged from 0-72 and they were, therefore, transformed to square roots for a comparison of the means. The results are shown in Table V.

All differences are significant except between the egg counts in oats, potato ridges and potato sides and bottoms on a basis of superficial area, but when the actual horizontal area is considered, the difference between the numbers of eggs laid in the oat flat and the potato flat is significant. It is interesting to note that the potatoes had been ridged up when wet and a hard, smooth crust had formed. In spite of this, equal numbers of eggs were laid here as in the loose and cloddy tops of the ridges.

TABLE V.

Numbers of Eggs laid in different Crops, 1943.

Crop	15th July	10th August		
	1,000's per acre	Mean no./sample	Range	1,000's / acre
Wheat	176	1·6	0–5	400
Oats	1,400	13·7	2–41	3,560
Roots	560	4·0	0–14	1,040
Potatoes—				
Ridge tops...	1,960	18·9	2–55	7,650
Ridge sides and bottoms		21·9	0–72	

The numbers recorded for the roots are probably on the low side as some of the eggs would be buried deeper than the 1-inch sampling level during scruffling and hoeing. In 1944, the numbers of eggs found in the second inch after these cultivations was generally about one third the number in the top inch.

Apart from the relatively low numbers in the wheat, all other results were rather surprising. The general impression has hitherto been that eggs laid in potato fields were laid either before the tops met in the rows or after the lifting of early varieties, and this is suggested in the literature (Molz 1918, MacDougall 1932, etc.). For this reason the sowing of mustard after early potatoes has been advised and appears to have met with some success, though the explanation would not appear to be as simple as previously thought.

It has also been generally assumed that a light open soil would be ideal for oviposition (Rostrup 1924, etc.), but the flies apparently preferred the more compacted and cloddy soil under the potatoes to the looser and finer soil between the plants in the root flat. Finally, as already stated, the flat of oats had a good cover of weeds and yet the flies laid readily in it.

Later Samplings in 1943.

In order to determine the effect of lifting the potatoes on the depth distribution of the eggs, five 4-in. core samples to a depth of 10 inches in four separate layers, were taken in October. Only six eggs were found in the five samples from the top $2\frac{1}{2}$ inches, 1 in the $2\frac{1}{2}$-5-inch layer and none below that. The effect of the potato spinner is mainly to transfer the top half of the ridges into the furrows so that the lowest eggs should be those laid in the furrow bottoms which, after lifting, will be about 5-6 inches below the surface. The 7 eggs in five samples represents only 700,000/ac., a decrease sufficiently big to be unlikely to be due to chance despite the small number of samples. A series of ten surface samples to a depth of 1 inch gave a figure of 417,000 eggs per acre.

To decide whether the operations involved in potato lifting had been responsible for this large decrease, a series of ten superficial samples was taken in the oat flat, the stubble of which had been cultivated once but not seriously disturbed

and here the number of eggs found was only 260,000 per acre. As the field referred to in the first part of this paper, which was less than half a mile away, had a larval population of about 580,000 per acre, it seems reasonable to suppose that a very large decrease in egg numbers did take place in August and October.

1944 Results at South Duffield.

In 1944 the number of flats sampled was increased and the number of samples per flat was reduced to ten. Unfortunately the numbers of eggs found were much lower and the differences between the numbers laid in different crops were not so marked. Because of this, samples taken on different dates and in different flats of the same or similar crops, have been grouped together. The flats chosen were all near the wheat field described in section 1 and are shown in fig. 3 of a previous paper (Gough 1946). The samples were taken in September and the results appear in Table VI.

TABLE VI.

Numbers of Eggs laid in different Crops in 1944.

Crop	No. of samples	Mean no. eggs/sample		1,000's/ acre
Wheat and Oats. (B, J, K.)*	30	0·067± 0·0464		17
Mangolds and Sugar Beet. (E, L.)	30	1·033± 0·3571		270
Swedes. (C, D.)	30	2·267± 0·4496		592
Carrots. (F, G.)	30	4·100± 0·8338		1,070
Potatoes (A), tops of ridges	40	9·500± 1·119	6·45 ±0·82	
——— bottoms and sides	20	1·500± 0·2468		1,612
Potatoes on wet soil. (N)				
Tops of ridges	20	0·4 ± 0·234	0·323	81
Bottoms and sides	20	0·15 ± 0·15		
Potatoes ½-mile away (not in Fig. 3) Tops ...	10	7·3 ± 0·680	5·79 ±0·92	
Bottoms and sides (Exp. field)	20	3·15 ± 0·7346		1,447

* Letters refer to Fig. 3 in previous paper (Gough 1946).

Thus the results of the two seasons are not altogether similar but they have some common features. In both years normal, close cereal crops had a negligible egg population whilst potatoes had the highest population, though, in 1944, it was barely significantly different from that on carrots which were not examined in 1943. During oviposition the carrot foliage only covered a small proportion of the ground. The difference between swedes, and mangolds plus sugar beet, is only doubtfully significant as is also the difference between swedes and carrots. In 1944, the leaf growth of the swedes during the time of oviposition was far in advance of that in 1943. Thus, in this area, a covering growth does not seem to discourage egg laying, provided that the soil close to the ground is not densely covered.

The small number of eggs found in the very wet potato field shows that soil differences alone probably play an important part in the choice of oviposition sites. Crüger and Körting (1931) also adduce evidence of fewer eggs in moister soils.

Later Samplings at South Duffield in 1944.

After the potatoes in field A and the experimental field had been lifted, samples were taken with a 4-inch borer to a depth of 8-9 inches. The results are shown in Table VII.

Though there was an apparent increase in both fields since the earlier examination, the only significant increase is between the counts of 22nd September and 28th November on the experimental field. This might be due to more efficient examination of the soil but is more probably due to the difficulty of accurately transforming the count from superficial to horizontal area as the ridges and furrows were very irregular. It must be assumed that whatever the reason the count based on surface samples in September was considerably underestimated.

TABLE VII.

Later Samplings for Eggs at South Duffield (1944).

Field	Date	Mean No./sample and S.E.	1000's/ac.
A.	22nd Sept.	6·45 ± 0·82 (surface)	1,612
A.	25th Oct.	3·8 ± 0·60 (4-inch core)	1,900
Experimental	22nd Sept.	5·79 ± 0·92 (surface)	1,447
Experimental	25th Oct.	3·7 ± 0·47 (4-inch core)	1,850
Experimental	28th Nov.	4·5 ± 0·52 (4-inch core)	2,225

Results in other Areas.

Other areas sampled in 1944 were at Stokesley and Sunk Island on fallows and at Dirtness Bridge farm after potatoes and sugar beet. With the exception of the sugar beet field, where surface samples were taken, all the samples were 4-inch cores taken to the depth of ploughing or cultivation. The results are shown in Table VIII.

TABLE VIII.

Egg Counts in Areas other than South Duffield (1944).

Place	Crop	No. samples	Mean No./sample and S.E.	1,000's/ac.
Stokesley	Bare fallow ...	10	1·10±0·504	550
Sunk Island ...	Bastard fallow	20	1·700±0·4926	850
,, ...	Bare fallow ...	20	3·850±0·8813	1,925
,, ...	Potatoes ...	20	1·050±0·2855	505
Dirtness Bridge ...	Potatoes ...	10 (double)	5·200±0·8665	1,300
,, ,, ...	Potatoes ...	20	2·600±0·4378	1,300
,, ,, ...	Sugar beet ...	10 (surface)	4·900±1·320	1,280

The figures generally are of the same order and the similarity of the numbers on three different fields at Dirtness Bridge is striking. On the other hand, the differences between the three fields all within a few hundred yards of one another at Sunk Island are also worthy of note. The bastard fallow was ploughed during the last week in July which suggests that either the freshly turned-over land was not so attractive to the flies or that some egg laying had already taken place. Similar results were, however, obtained in 1945 when it was known that the flies were not laying at the time the bastard fallows were ploughed. The smaller number of eggs on the potato field is also interesting and confirm the observation that on this type of land only very slight attacks occur after potatoes. The possibility that the fly has rather different habits on heavy land is worthy of investigation but the amount of information so far available is very limited.

The Possibility of using Egg Counts for forecasting Outbreaks.

It is interesting to consider if estimates of egg population would be of value in forecasting the effect of wheat bulb fly on the ensuing crop. This possibility was discussed by Bremer (1929) and studied in more detail by Crüger and Körting (1931). Their estimates of the number of eggs and the percentage damage to the crop (which they admit will depend on its thickness) were both based on a rather small number of samples, but the amount of damage did appear to be related to egg number. Even fewer than 100,000 eggs per acre resulted in appreciable damage amounting to 20 per cent. of the plants and about $1\frac{1}{2}$-million eggs per acre resulted in 50 per cent. of the plants being destroyed. They point out that they have no evidence as to the effect of the season on eggs in different localities and conditions and Bremer (1929) stated that in October 80 per cent. of the eggs found were empty or dead for unknown reasons. This is a similar figure to that observed by the present writer in 1943, though the eggs here completely disappeared. In fact, though much higher numbers of eggs were laid in 1943 than in 1944, the number surviving in November was much higher in the second year, which was consistently wet during and after oviposition. It would, therefore, seem advisable that estimates of egg populations should be made fairly late in the year, and even then there appears to be a somewhat variable reduction in numbers up to the time the plants become infested by the larvae. The similarity of numbers recorded on neighbouring fields would also make the selection of less heavily infested fields difficult or impossible.

Many observations have been made on the continent as to the importance of the previous crop, *e.g.*, Kleine (1915, 1918), Becker and Blunck (1927), Crüger and Körting (1931). A study of their conclusions and tables shows that the most attractive crop for oviposition varies from place to place. Most of the authors conclude that it is not the actual crop which is important but the condition of the soil at the time of oviposition. The implication is that soils are attractive because they are exposed during the egg laying period, but this is certainly not the case in Yorkshire potato fields. It may be that provided the space just above the soil is open the shade or cover given by the upper leaves has little influence, but this suggestion would hardly explain the large numbers of eggs found in the weedy oat flat in 1943. A more detailed study of the factors influencing oviposition in various districts would be desirable.

Many attempts have been made to correlate weather in July or August with damage in the following year, but two diametrically opposed views exist. One is that an epidemic is likely to occur after a hot dry summer (Petherbridge, 1921; Ministry of Agriculture, 1943) and also suggested to the author independently by two Yorkshire farmers, and the other view is that heavy attacks follow cool moist summers (Kleine, 1915, 1918; Rostrup, 1924). These authors do not necessarily support either view, but at least state that they have met it. The explanations proposed in the literature are (1) a hot dry summer is favourable for the flies and oviposition, and (2) after a moist cool summer, the soil is wetter and there is not the same tendency for the eggs to be killed by desiccation. Both explanations seem plausible and the views are not irreconcilable. They could account for the lower egg numbers observed by the present writer in 1944 which was consistently wet, and the great reduction in egg numbers between August and October, 1943, a relatively dry year.

However, such speculations are not so reliable as observations carried out over a number of years and Rostrup (1924), Schnauer (1929) and Bremer (1931) have recorded the results of such observations. Rostrup could find no connection between August weather and attack and both she and Bremer stressed the effect of weather on the crop rather than on the pest. Rostrup correlated the intensity

of the attack with the weather in autumn, winter and spring, over a period of 20 years, and found that epidemic attacks were recorded whenever two or three of these seasons were unfavourable for the crop. Schnauer was also unable to relate attacks to any climatic factors (including those mentioned) in the year of attack or the previous year.

Most of the present writer's information also suggests that the actual number of larvae is less important than the effect of soil and weather on the crop, but it is difficult to be certain when only general and incomplete records of crop damage are available. Accurate counts of eggs and larvae and also accurate estimates of the infestation each year for a number of years would be needed to settle the point. Summing up, however, it seems unlikely that egg counts would be of much value in forecasting outbreaks.

Natural Mortality at various Stages.

From the information obtained during this study, some tentative suggestions can be put forward on the occurrence of natural mortality in wheat bulb fly populations. Equal numbers of males and females emerge from puparia in the laboratory. The numbers of females caught in one locality decrease during the four weeks needed for the maturation of the eggs and although this decrease is partly due to dispersal, a number of flies are likely to die or be killed. In a wet season especially, the adults are liable to be killed by a fungus of the *Empusa* type but, even in 1944, which was consistently wet, the proportion of flies attacked appeared to have been low. The number of eggs laid by each surviving female probably does not much exceed an average of thirty. A high proportion of eggs are laid in fields which will not be cropped suitably and in which other potential hosts do not occur in sufficient numbers. In 1943 but not in 1944, a marked decrease (of the order of 90 per cent.) of the eggs occurred in the autumn and a similar reduction was noted by Bremer (1929). In his case the reduction appears to have been due to predators, as empty shells were found. The decrease recorded by the present writer may have been due to desiccation but if so, most of the shells should have been recovered. It could not have been due entirely to intrinsic factors such as lack of fertilisation, as a fairly high proportion of 1943 eggs, kept in the laboratory, hatched out successfully. In 1944 approximately 25 per cent. of eggs obtained in the field were considered non-viable when recovered and of the remainder approximately half hatched successfully.

The proportion of larvae hatching which found and infested plants in 1945, varied from a little under one-half to one-fifth in different places. There appears to be little mortality up to the time at which the larvae start moving from shoot to shoot. Between this time and pupation there is again a variable reduction ranging up to about 70 per cent. No information has been obtained on losses during the pupal stage. No insect parasites appear to have been recorded by any author, though Gemmill (1927) has found a Nematode parasite of the larva and occasionally the present writer has found a predacious Dipterous larva and the remains of a wheat bulb fly larva in damaged shoots. It must be admitted in conclusion, that practically no information exists of the occurrence of the fly on wild host plants.

Summary.

A detailed quantitative study of the incidence and development of an attack of wheat bulb fly on a field in East Yorkshire is described. The numbers of larvae, puparia, plants, and shoots, and the percentage of plants and shoots attacked, were estimated on various dates. This information is graphically summarised in fig. 1. Similar information was obtained from other fields in 1944 and 1945. No single factor could be correlated with the effect of the attack on the crop.

The number of larvae ranged up to nearly 600,000 per acre, but high numbers did not invariably result in a poor crop. A high percentage of plants or shoots attacked was not necessarily associated with crop failure. The number of shoots per plant at the time the larvae hatch was important and in some cases attack stimulated tillering. It is suggested that a study of the rate at which damage occurs would lead to a better understanding of the reaction of any crop to pest attack.

A technique is described for estimating the number of eggs laid in the soil and the results for various crops and places are recorded. In 1943 over $7\frac{1}{2}$ million eggs per acre were laid in a potato field but an unexplained reduction of about 90 per cent. occurred in the autumn; the numbers laid in the same district in the following year were about 2 millions per acre but no large reduction occurred. In different areas between one-half and one-fifth of the eggs hatched successfully and infested plants. The possibility of using egg counts to forecast outbreaks is discussed and it is concluded that it is not likely to be successful. A brief account is given of the known natural mortality of the fly at various stages.

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OBSERVATIONS ON THE CHAFER GRUB PROBLEM IN THE LAKE DISTRICT.

By R. A. Harper Gray, W. V. Peet & J. P. Rogerson.

(Plate IX.)

An account is given of an investigation into the prevalence of damage to fell grassland in the Lake District, caused by the larvae of the Garden Chafer (*Phyllopertha horticola*, L.). The paper is divided into three main sections, *viz.*, (1) entomological (2) distribution of the Chafer population, and (3) observations and trials pointing to control. The first section comprises a study of the biology with some notes on the morphology of the insect. The section dealing with distribution is supplemented by a map indicating the chief areas of population, and details are given of observations and manurial trials pointing to control, to which is added a note on natural control. Where it is possible to carry out, harrowing and reseeding, with judicious manuring, is recommended as the most practical method of avoiding large-scale damage by Chafer grubs to the fell grassland.

Introduction.

Although it is only within comparatively recent times that farmers in the Lake District have become seriously alive to the extensive deterioration of fell grassland due to Chafer grub attacks, it would seem that there has been more or less appreciable annual injury done within the memory of the present local farming community. There are, indeed, farmers who remember damage done by the grub to hill grassland over half a century ago, which, according to some, was as severe then as it is now. The earliest record of any noteworthy appearance of the beetles, or " bracken-clocks ", in Britain is apparently that of Curtis who cites 1814 as a year when they occurred " in immense numbers " in an area near Swansea. In his " Farm Insects " (1860), Curtis also describes the beetles as being " exceedingly abundant in the autumns of 1839 and 1840 in Hampshire and Gloucestershire, and again in 1844 in various localities ". Later, Miss Ormerod in her annual Reports, dating from 1877, refers to a specially heavy infestation in 1885. Her observations are, in the main, concerned with the adult and the injury done by it amongst orchard fruit trees and bushes, though she mentions the harm done by the larvae to grass in parks and pastures. Fowler (1890) states that the species " is sometimes very destructive to pasture land and does considerable damage to gardens ". In his First Report (Economic Zoology, 1903) Theobald records the larvae of *P. horticola* as being fairly general in Wales " where the beetle is known as Cock-y-bonddu ". Since then it has been noted as being a serious pest on the hill grassland in Wales, and Yorkshire, as well as in Westmorland and Cumberland.

In 1935, complaints of considerable damage were received at King's College, Newcastle-upon-Tyne. A farmer at Glenridding on Lake Ullswater, alluded to abnormally serious attacks on his hill meadow land. From further south, in the area north of Lake Windermere, *e.g.*, Ambleside and Rydal, accounts of severe grub damage were reported, as also from Grasmere, and, further west, Langdale Pikes amongst other areas. In the meantime visits were made, especially to the Rydal and Glenridding areas in the course of which much information was obtained from local farmers. Notes have been accumulated from this source and also from tentative trials carried out against the grubs with different substances on the hill grassland, apart from investigations made in the laboratory. In

1938, thanks to a grant from the Ministry of Agriculture, it was possible to have an observer (W.V.P.) stationed at Rydal for the purpose of making field observations, occupying six months (April to September) in each of the years 1938 and 1939. These observations confirmed and added to those already made, and they are incorporated in the present paper, the preparation of which was held in abeyance during the European War, when work in the field by the observer was interrupted by the duties required of him in the Royal Air Force.

The writers desire gratefully to acknowledge the help given by Sir John Fryer in making possible the appointment of an observer (W.V.P.), and in offering useful suggestions for the work at the outset of the investigation. They also desire specially to thank Professor J. A. Hanley, King's College, for the practical interest he took in the investigation, particularly in connection with the arrangement of the plots for manurial trials, and the obtaining of population counts in an area of fellside grassland at Rydal.

I. Entomological.

A. Notes on Life-history.

(1) *Flight Period.* On 17th May, 1938, several pupae and a few adults were found well down in the soil by searching on the fell-side, but none of the latter had been observed in flight at that date. During the last week of May the weather was cold with almost continuous rain, but on 1st June there was a fair period of a few hours in the forenoon, during which it was possible to observe in one part of the field the continuous appearance of beetles issuing from the soil. Very few were seen mating and none could be found on the bracken. As the beetles did not appear to have commenced their upward movement on the day before their emergence above ground, the time taken for this cannot be more than a few hours at most. In the course of an hour or so, about mid-day, the swarm of beetles had disappeared and a close examination showed that they had again entered the soil where they were found lying apparently dormant at a depth of $\frac{1}{4}$-$\frac{1}{2}$-in.

This sudden change in behaviour was very striking and it appeared to be a normal procedure. Several beetles were lifted and placed on the surface where they lay still for about a minute, and then began to re-enter the soil.

The flight period, in 1938, was practically over by 24th June. On that date only a few beetles, nearly all females, could be found on the bracken well up the fell-side. Dead beetles were frequently noted.

In 1939, beetles were first seen in flight on 30th May, and on the following day many more emerged, noticeably on the lower levels of the fells. As in the previous year the beetles were active only during the forenoon, although the weather remained very hot with bright sunshine throughout the day.

Mating was not observed to take place until 3 or 4 days after emergence from the pupae, after which period it continued intermittently for a few days. The adults live for 10 to 14 days, the males as a whole living rather longer than the females and the percentage of males tending to increase throughout the period.

On the fell-side the flight period was at its height about a week later than on the fields at the foot of the fell-side. A delay of some days also occurred on situations with a northerly aspect as compared with those facing south. This was particularly noticeable on the slopes of the numerous and fairly large brows or "breasts" of hills abounding in the affected area.

On each successive day of the flight period the activities of the beetles were continued for a longer period of time, reaching a maximum between the hours of 11 a.m. and 1 p.m. Throughout the afternoon, flying, feeding and mating diminished, and no activity was observed in dull weather. It should be noted that pairs of insects were seen apparently in copula at any time of the day, but

on examination these appeared to be quite inert except during the period mentioned. Congregating on the bracken does not take place till the latter half of their life. A certain amount of feeding takes place when they are on the bracken, and the lower surfaces of the fronds are particularly favoured for resting and mating. The beetles have also been observed feeding on many kinds of trees, bushes, shrubs, flowers and grasses, and they are sometimes troublesome in cottage gardens where roses and fruit trees have suffered damage.

Exceptionally dry weather conditions coincided with the most active part of the flight period in 1939, there being practically no rainfall at Rydal during May and the first ten days of June. As a result the ground was baked hard, the grass being scorched and apparently killed in several places. It was a common occurrence to find females lying dead on the fields below the fells, and examination of these in the laboratory showed the ovaries to contain mature eggs. Other females were seen to be trying to penetrate the hard baked surface of the turf. After each unsuccessful attempt a short flight was made to another spot where again an effort was made to enter the soil, and it seems likely that when such abnormal soil conditions occur the mortality of the beetles on the lower levels may be high. The proportion of males to observed females tended to increase during the flight period, a fact which may be partly explained by the re-entry of females to the soil for oviposition:—

		Adults	*Males*	*Females*	*Ratio*
31st May, 1939	...	277	214	63	$3\frac{1}{2}$: 1
9th June, 1939	...	223	206	17	12 : 1

(2) *Oviposition and incubation Period of the Eggs.*—Sexual maturity of the adults is reached from 3 to 4 days after emergence from the pupae. Pairing then takes place and continues intermittently for at least another three days, mostly during the forenoons. Different males may copulate with the same female. The females enter the soil to lay their eggs which are deposited at a depth of 1 inch to 4 inches. A good average over this field would be $2\frac{1}{2}$ inches. Variation in depth does not occur over small areas where the soil conditions are the same but where there is a greater depth of soil, the eggs are deposited lower down. During one period of searching, four eggs were found on the soil just below the matt.

Only one series of eggs is laid, these being deposited singly in June usually at a depth of 2 to 3 inches. Dissections of adult females showed the number of eggs in the ovaries to be variable. For example, the numbers taken from the ovaries of 20 females collected at random and dissected in the laboratory ranged from 6 to 17, *viz.*, 6, 8, 12, 11, 16, 17, 13, 16, 6, 12, 9, 15, 16, 16, 8, 10, 12, 16, 7, 13.

Pot experiments were carried out in the open at Rydal in order to determine the incubation period of the eggs, and the results corresponded, in the main, with observations made in the field. The weather at the time was somewhat cold and wet. The time elapsing between the laying of eggs and hatching in the field varied from 27 to 30 days. In one pot 16 eggs, deposited by a single female on 22nd-23rd June, hatched out as follows: 7 on 20th July, 5 on 21st and 2 on the 22nd. Two eggs failed to hatch out, but they may have been injured in handling.

(3) *The Grub* (fig. 1).—On hatching from the egg, with the help of a so-called "egg burster" (p. 460), the larvae remain for some time at about the same level as the eggs, during which it is likely that they subsist on very fine vegetable matter. They increase in size, however, at a fairly rapid rate, feeding on the grass roots, and by the middle of August ecdysis has taken place and grubs of the second instar are found feeding actively near the soil surface. From then onwards until near the third ecdysis the grassland in various parts of Lakeland shows, from a distance,

the discoloured areas and patches typical of Chafer grub attack. On close examination this unhealthy appearance is found to be due to the destruction of the grass roots by the grubs, the result being that the turf thus loosened can be readily removed by hand. The soil underneath is also of a loose spongy texture, which is noticeable to anyone walking over an affected patch.

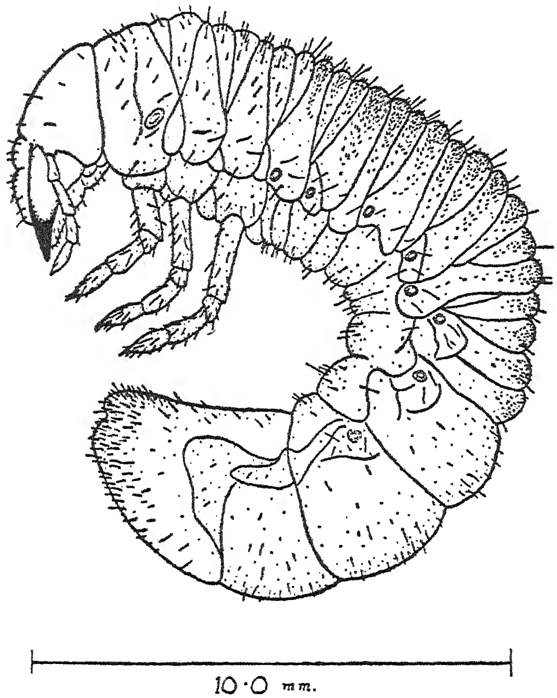


FIG. 1.—Third-instar larva of *P. horticola*.

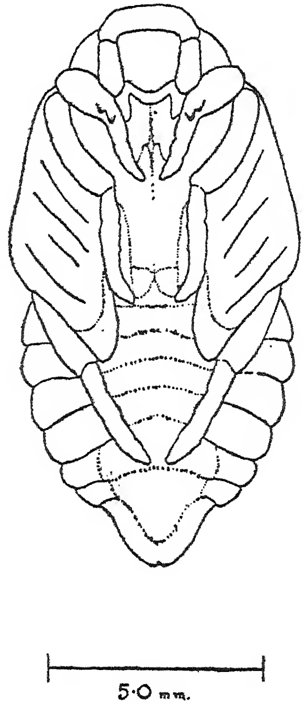


FIG. 2.—Pupa of *P. horticola*.

Where there is a dense population of grubs the whole root system may be thus destroyed. The sum total of the damage done in the infested area in any one season is difficult to assess. Losses in the plant population are masked by the growth of other grasses and recolonisation by new plants from seed so that the extent of injury becomes obscured. Deterioration in the botanical composition of the grassland, and consequently in the feeding value of the pastures, and their stock-holding capacity, is constantly taking place. The damage done as a result of the predatory activities of rooks is particularly severe, the turf being completely destroyed. This surface damage is, of course, to be attributed directly to the grub population. In such cases the botanical colonisation is almost entirely by weeds, including particularly sorrel, plantain and yarrow, the establishment of which in ever increasing numbers is not the least serious aspect of the problem. The injury to the turf resulting from the destruction of the roots by the grubs is intensified by conditions unfavourable to the plants. Thus the relative extent of the injury to pastures may be correlated with deficiencies in the fertility of the soil, with organic food reserves of the plant, or a combination of such general factors influencing growth.

There is in each year only one generation of *Phyllopertha*, the dormant period commencing towards the end of October when fully fed grubs begin to abandon the roots of the grasses and descend to the subsoil level for overwintering. This level varies greatly in the Lake District and the dormant larvae are found resting on the gravel bed at depths varying from 2 inches to 6 inches. In the Lake District

the more shallow soil occurs on the slopes of the frequently occurring " brows " or " breasts ", such situations being heavily populated. The mean depth at which the overwintering larvae were found was about 4 inches. The dormant period continues until April and no further feeding takes place. A prepupal stage precedes the pupal stage proper, the prepupa being enclosed in the last larval skin, the whole lying within an earthen cell. The majority of the larvae lie in a curved position with the head uppermost.

(4) *The Pupa* (fig. 2).—The pupal stage proper is reached towards the end of April and the beginning of May. Thus, during the first week of May, 1939, only a few exceptions could be found of late individuals in the pre-pupal stage. The majority of the pupae were found at subsoil level, which varies greatly in the Lake District on account of the rocky nature of the terrain where bare rock is often exposed. In such areas, particularly those facing south, pupae occur at a depth of 2½ to 3 inches, practically resting on the gravel bed. The greatest depth was 6½ inches which represents the subsoil level of the area. No pupae were found at a depth of less than 2 inches, the average depth in the Rydal area being 3-4 inches.

The pupa, protected by the skin of the last larval instar and enclosed in an earthen cell, is of the " free " or exarate type in which wings and legs are " free from any secondary attachment to the body " (Imms). Movements made by the pupa are thus active and strong.

B. Notes on Morphology.

(1) *The Egg*.—The egg of *P. horticola* is spherical in shape when laid, becoming later slightly subovate. It is dull white in colour and thinly coated with a glutinous substance secreted by the colleterial glands to which fine particles of soil may adhere. The surface of the chorion, through which the embryo larva can be seen in opaque outline, is matt and finely granulose. As the larva inside develops, the dimensions of the egg alter somewhat, the length slightly exceeding the breadth. Measurements of six eggs laid by one of the females kept in the laboratory for observation, made at about equal intervals, showed an average length of 1·48 mm., and an average breadth of 1·33 mm. The actual lengths and breadths as given below showed slight variations:—

Egg	1	2	3	4	5	6	Av.
Length	1·5	1·4	1·8	1·6	1·4	1·2	1·48 mm.
Breadth	1·2	1·3	1·5	1·5	1·3	1·2	1·33 mm.

Eggs collected at random over the fell grassland at Rydal gave somewhat larger measurements. Thus the average length of six of these was 1·7 mm. and the average breadth 1·45 mm. the actual figures being:—

Egg	1	2	3	4	5	6	Av.
Length	1·8	1·7	1·7	1·7	1·7	1·6	1·7 mm.
Breadth	1·5	1·5	1·4	1·2	1·6	1·5	1·45 mm.

(2) *The Hatching Spine or " Egg Burster "*.—In the course of the investigation, eggs were placed on damp blotting paper in petri dishes for observation in the laboratory. It was thus possible to observe under the microscope the minute arrangement by which the embryo wears away the egg shell, and so emerges to begin its first larval instar. It consists of two chitinous projections situated one on either side of the third thoracic segment, along with a bristle, one below and the other in front of the projection (fig. 3). As one would expect from the shape of the egg, the embryo lies in a curved position, with the head and tail regions approximating, but it is able to exercise sufficiently forceful movements by which

the mechanism is pressed against the shell wall at frequent intervals to form an abrasion and finally a break in its continuity through which the larva escapes.

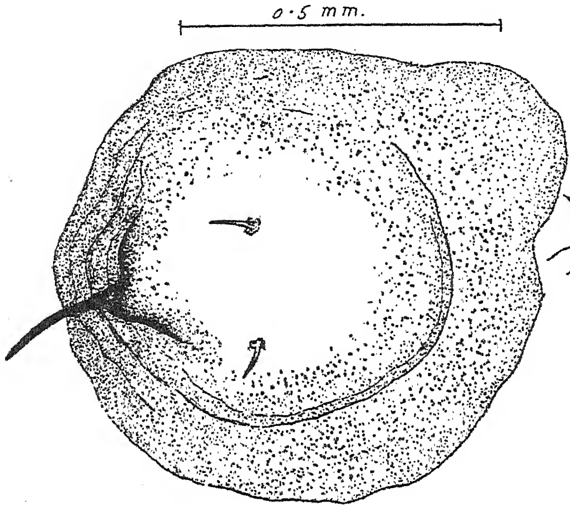


FIG. 3.—The hatching spine or "egg burster".

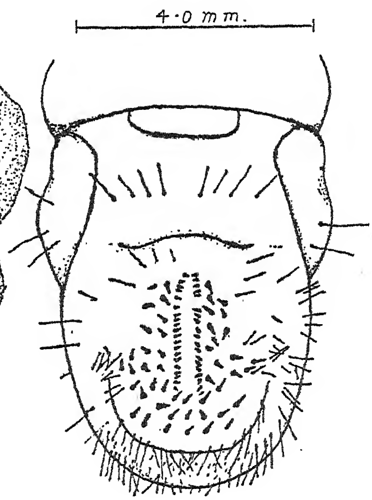


FIG. 4.—Ventral aspect of segments 9 and 10 of the third-instar larva of *P. horticola*, showing arrangement of the spines.

It is difficult to observe the individual parts played by the chitinous projections and the bristles. Rittershaus (1924) suggests that the function of the bristles is to form a small perforation preparatory to the abrading and tearing action of the chitinous projection. The small opening would allow of an outflow of some of the fluid within the shell which Rittershaus describes as appearing slowly at first as drops (tropfenweise), the flow increasing through the subsequent action of the tooth-like chitinous projection.

3. *Larval Development—Ecdysis.*—The application of Dyar's law throughout the larval period of growth, involving as it did the measurements in millimetres of the head widths of 210 dead larvae, showed that *Phyllopertha horticola* after emerging from the egg undergoes three moults or ecdyses, thus giving rise to three instars as shown below:—

	Mean	*Max.*	*Min.*	*Diff.*
1st instar	1·22	1·42	1·00	0·42 mm.
2nd instar	1·93	2·08	1·75	0·33 mm.
3rd instar	2·98	3·25	2·66	0·59 mm.

Larvae of the first instar persisted up to the end of August after which period the majority of larvae found were in the second instar and by the 5th of September nearly all larvae examined were in the third instar. Reference has already been made to a prepupal stage which in *P. horticola* occurs after a hibernating period lasting until March or April. The prepupal stage would appear to be of short duration. At any rate on 17th April larvae kept in the laboratory were found showing, when touched, active movement in the soil, but in the first week of May the insect could be found only in the pupa stage, with a few exceptions of apparently late individuals in the prepupal stage.

The ventral aspect of the larval abdominal segments 9 and 10 differs from that of the three genera *Melolontha, Amphimallus* and *Serica*. It approaches *Melolontha* most closely in the arrangement of the anal orifice and of the parallel rows of spines in segment 10 (fig. 4). The spines, however, meet obtusely at the ventral line, whereas in *Melolontha* they meet acutely.

II. Distribution of the Chafer Population.

(*a*) *General.*—The grassland areas showing most damage from attack of the Garden Chafer grub include farms round and about the head of Lake Ullswater, *e.g.*, at Glenridding and Patterdale, towards Lake Brotherswater approaching the Kirkstone Pass, and on fell grassland on both sides of the road leading from the south of the Vale of St. John's on the way to Ambleside and Windermere where along with Rydal and Grasmere the damage is also severe. Towards the west, fields showing major damage occur in the Langdale and Eskdale fells, as well as along the Duddon Valley in South Cumberland (*see* map, fig. 5). Appreciable damage has also been noted in the Buttermere district (1945).

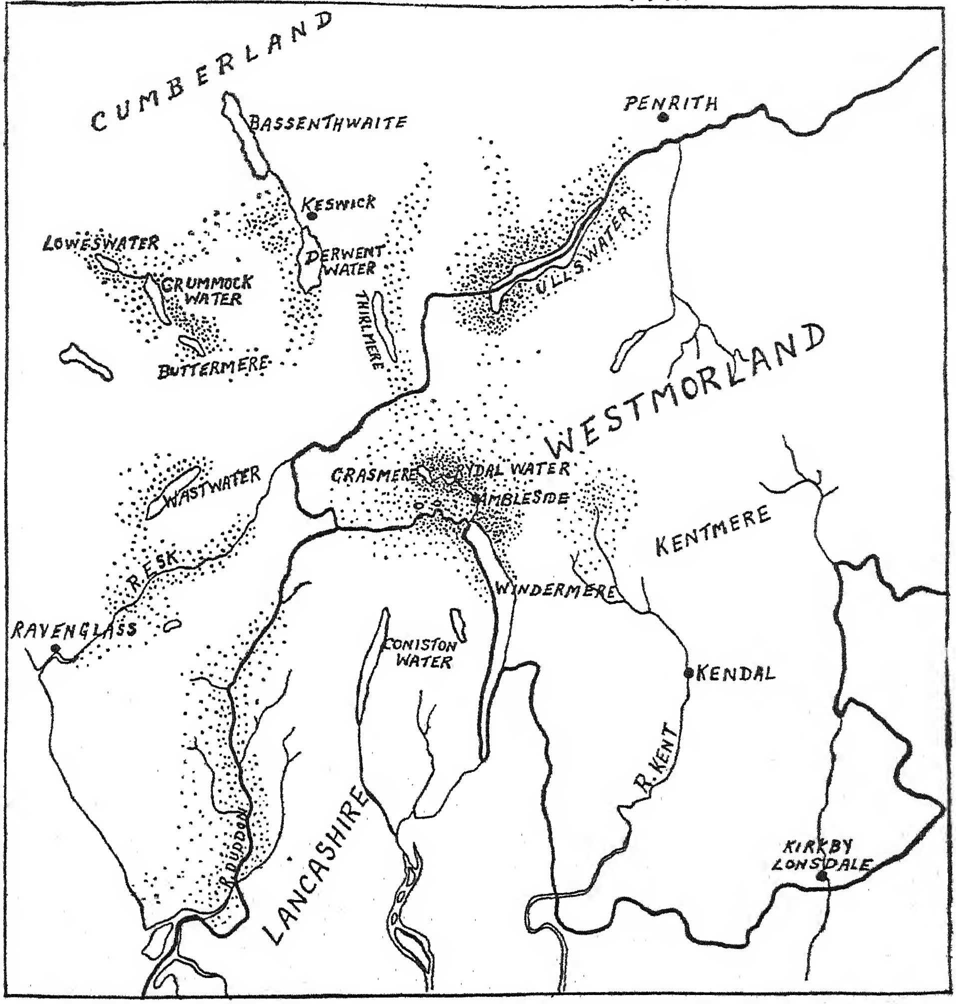


FIG. 5.—Map showing grassland areas suffering most damage from attack by *P. horticola*, L.

There are, besides, areas, *e.g.*, Kentmere, where the grubs can be found, though so far not occurring in sufficient numbers to cause appreciable injury to the grass. A questionnaire sent to the district officers and the chairmen of various district committees, requesting amongst other things the names of affected fell-side farms

in their areas, showed that to the north of a line drawn through Silloth, Wigton and Penrith, there was no recognised Chafer "problem". Further south some fell-side farms lying between Cockermouth and Keswick were affected, and it is also known to occur to the south of Lake Derwentwater, and in Borrowdale.

A feature of Chafer grub damage is its lack of uniformity. An infested area is usually attacked only in patches which may vary in extent from a few square yards to several acres. A similar disparity of degree of infestation may occur even in adjacent fields; whilst one may be severely attacked, the other may show little sign of damage. Various factors may contribute to the occurrence of such variation of grub densities within a small area. It would appear that either the beetles have selective egg-laying habits or, should the egg-laying be indiscriminate, eggs may fail to hatch in certain situations, and there may also be a higher mortality among the larval stages. It has been observed that the ovipositing females have a marked predilection for poor spongy turf. Thus, variations in distribution can be partly explained on the basis of a selective discrimination on the part of the adult females in choosing a point of entry into the soil for egg-laying. This would explain in part why the poorer parts of the grassland are more susceptible to attack than those which have been improved by grazing and fertilisation and which are, therefore, more compact.

In an infested area the contours are often very uneven, and it has been observed that the grubs are most numerous where the gradient increases, as in the neighbourhood of a slope having a southern aspect. In such a situation, the soil is comparatively shallow and the herbage of a poor type tending to develop a matted growth which is avoided by stock. Such an environment is particularly favoured for the laying of eggs, and would appear also to favour the development of the grubs, since they are able to move more freely amongst the roots of the grasses. It has been observed by examination in the field that larvae in such situations develop more rapidly than those which are found in comparatively good turf which has benefited by grazing and treading.

Observations made in 1939 indicated that the physical characteristics of the turf may be a limiting factor in the distribution of the insect population. In that year, owing to the exceptional drought, the turf offered an abnormally high resistance to the entry of the ovipositing beetles. On a well grazed and comparatively good pasture, numbers of gravid females were found which had apparently been unable to enter the soil, and had died in the open. Other beetles were observed in the act of attempting to penetrate the turf and after an unsuccessful effort were seen to make a short flight and make a further attempt at another spot.

(*b*) *Local*.—At Crow How Farm, Rydal, an infested area of approximately $15\frac{1}{2}$ acres, partly fell-side and partly level grassland, was utilised for estimating a local population. A technique based upon that used in the Wireworm Survey was adopted. At the same time an attempt was made to correlate the grub population with the kind of soil, the presence or absence of bracken, trees, grasses, and damage by birds.

An average of eleven 1 square foot portions of turf, twenty yards apart were removed in each of six rows, also twenty yards apart. On the level portion, seven 1 square foot portions of turf were removed in each of ten rows similarly spaced. On the fell-side alone, 172 grubs were found in the sixty six 1 square foot samples, representing an estimated population of 113,520 grubs per acre. On the level portion 108 grubs occurred in the seventy samples giving an estimated population of 67,207 grubs per acre. The comparative numbers of grubs existing under the different natural features of soil, etc., showed most grubs where birds were at work on the turf, more in dry friable soil than in distinctly moist soil, and more in parts bordering on bracken than in areas at a distance from it (Table I).

TABLE I.

Feature	No. of samples	No. of grubs	Average no. per sample
Soil, dry, friable	24	69	2·8
Soil, moist...	42	51	1·2
Near bracken	47	112	2·4
Away from bracken ...	73	132	1·8
Bird damage	17	117	6·8

Counts made in 1938 and 1939 on plots marked out for manurial trials in the level field at the foot of the fell-side at Rydal showed a high grub population nearest to the fell-side, the numbers diminishing in the parts of the field farthest away from it, as shown in Tables II and III.

TABLE II.—Counts made in 1938.

1938

From Foot of Fell

5 0 / 10 / 6 2	4 7 / 1 / 4 2	3 2 / 3 / 0 6	10 6 / 4 / 4 2	12 17 / 4 / 3 9	126 grubs, or approx. 219,542 per acre
0 1 / 0 / 3 0	0 3 / 5 / 2 0	1 1 / 1 / 2 0	0 7 / 0 / 3 3	3 0 / 2 / 1 0	38 grubs, or approx. 66,211 per acre
5 1 / 3 / 0 2	0 3 / 0 / 2 0	2 0 / 0 / 2 4	3 1 / 6 / 0 0	1 2 / 0 / 3 2	42 grubs, or approx. 73,181 per acre
4 0 / 0 / 2 0	1 1 / 2 / 0 0	0 4 / 0 / 1 0	0 1 / 0 / 0 0	1 0 / 1 / 0 2	20 grubs, or approx. 34,848 per acre

Road to Ambleside

TABLE III.—Counts made in 1939.

1939

From Foot of Fell

4 0 / 0 / 2 0	2 3 / 5 / 0 0	0 4 / 2 / 2 0	6 3 / 0 / 0 4	1 7 / 0 / 0 3	48 grubs, or approx. 83,635 per acre
2 3 / 0 / 0 1	1 3 / 0 / 2 0	0 0 / 0 / 1 0	2 0 / 3 / 0 1	4 0 / 1 / 0 0	24 grubs, or approx. 41,817 per acre
0 3 / 0 / 5 0	0 0 / 1 / 0 0	0 2 / 0 / 2 0	3 0 / 1 / 0 0	0 0 / 0 / 2 0	19 grubs, or approx. 31,106 per acre
0 0 / 0 / 0 1	0 0 / 1 / 0 1	1 1 / 0 / 0 0	2 1 / 0 / 0 0	0 0 / 0 / 0 0	8 grubs, or approx. 13,939 per acre

Road to Ambleside

The comparatively small numbers of grubs per acre found in 1938 and the still further reduction in 1939 may be accounted for by the fact that the summer of 1938 was excessively wet causing much mortality amongst the beetles emerging from the 1937-38 generation. Another factor may be suggested, namely, the hard baked condition of the surface soil generally, caused by a spell of abnormally dry conditions prevailing during the most active part of the flight period in 1939 (p. 457).

In May, 1939, a series of four sets of counts of *pupae* was made proceeding upwards from the foot of the rather steep fell-side, *i.e.*, from 400 feet to over 800 feet above sea level. The numbers of pupae found in each square foot of turf are shown in the following table, a distance of 25 yards separating every two counts in the column:—

TABLE IV.

0	0	0	0	
0	0	0	0	
	800 feet (approx.)			
0	0	1	0	
1	0	0	0	
0	1	1	1	58,806 per acre
2	1	0	0	
3	2	3	2	
5	6	2	3	
6	4	5	3	
	600 feet (approx.)			
0	1	0	1	
1	0	2	3	
3	2	3	4	
1	0	1	2	
3	3	2	2	
0	1	1	0	74,052 per acre
3	2	0	0	
4	3	1	2	
1	1	2	2	
0	1	2	0	
3	2	4	1	
	Foot of fell—400 feet (approx.)			

No pupae were found above approximately 800 feet. The turves showing most pupae were almost all situated on a steep gradient. Comparatively flat areas with a greater depth of soil and growing a better quality of herbage, including clover, contained few pupae. Also, an increase in the average number of pupae occurred in the turves taken bordering bracken, and turves having a matt of sheep's fescue contained a high proportion of pupae. The lower half of the series of figures in Table IV indicates an approximate population of 74,052 pupae per acre, as compared with 58,806 pupae per acre in the upper part of the fell-side.

III. Observations and Trials pointing to Control.

Any methods suggested for the control of the grubs on the higher "fell" grassland, involving the application of insecticides must be considered impracticable on account of expense, difficulty of application and the danger to sheep feeding on the fells. Indeed, in the impoverished hill grassland of the Lake District, it would seem that the problem of dealing with the Chafer grub has reached a stage where it is concerned primarily with grassland improvement rather than with entomological control. Hence in the present investigation in which large areas were involved, the results of manurial applications in trials carried out and assessed by "evidence of the eye" would appear to be useful as at least indicating practical control methods. On a farm at Ambleside, a field that had received basic slag in the autumn of 1935 and kainit in May, 1936, showed an excellent herbage as

compared with grassland on poorer land on the farm, and on neighbouring farms. The grassland, indeed, as a whole, on this farm (mostly situated at a fairly low level) did not suffer from the Chafer grub to the same extent as for example, the grassland at Rydal. The land in question had from time to time received dressings resulting in some improvement of the herbage. On most farms in the grub-infested areas all that the land has received has been from the stock grazing on it, and there is no doubt that the vast majority of the hill grassland in Westmorland both near and at a distance from the farm buildings is in a similarly impoverished state. Samples of turves from experimental plots on the fell grassland at Rydal were kindly examined by Mrs. Clark, Lecturer in Agricultural Botany, who reported the prevailing species of plants as follows:—Field Woodrush (*Luzula campestris*), Sheep's Fescue Grass (*Festuca ovina*), Bent Grass (*Agrostis* sp.), Self-heal (*Prunella vulgaris*—several young plants), Narrow-leaved Mouse-ear Chickweed (*Cerastium triviale*), Wild White Clover (*Trifolium repens*—a few plants), Smooth Heath Bed-straw (*Galium saxatile*), Yarrow (*Achillea millefolium* —a few plants), Sedge (*Carex caryophyllea*), Moss (*Hypnum* sp.), Plantains and *Rumex* spp.

Further observations on this particular farm seem to confirm the above results, as regards kainit, in a field which received a dressing of basic slag in autumn, 1936, followed by a dressing of kainit in May, 1937. The grass here again showed well in October, with a marked absence of grub damage. Where basic slag was applied and *not* followed by a dressing of kainit the grass showed in October much grub damage. Kainit also showed good results in another field which was chain-harrowed and reseeded where bare patches were left over from the previous year's attack.

The centre of a field on the same farm was marked out in four squares which received respectively at normal rates per acre naphthalene, sulphate of ammonia, salt and kainit. Kainit left over was also spread on the top part of the field to the right of the plots. Here the kainit plot showed up best, and the extra part receiving kainit also contrasted conspicuously with the remainder of the field, which was severely damaged by the grubs. The sulphate of ammonia plot showed a somewhat rank growth; the naphthalene plot was clean and slightly better than the plot receiving salt. On this farm the results of the trials pointed to a lack of potash in the soil.

At another centre (Rydal) naphthalene was applied in July to three ¼-acre strips at rates of 5, 7 and 10 cwt. an acre respectively. No difference could be observed between the grass strips receiving the smaller amounts and that receiving 10 cwt. per acre, but a comparison with the surrounding untreated areas gave the impression that naphthalene had some slight effect in retarding the movements of the grub.

On the same farm mortality tests were made during the last week of August, 1938, on 1 square yard portions of turf with naphthalene, a proprietary article, salt, kainit and superphosphate, the turf in each case being carefully removed and the material sprinkled before replacing. After a week the turves were lifted and examined, as was also the soil underneath, when the results were recorded on 1st September as follows:—

Plot 1.—Naphthalene, 2 oz. per sq. yd.:—56 dead, 11 moribund, 3 unaffected (low down), *i.e.*, 80 per cent. killed, 95·7 per cent. dead and affected.

Plot 2.—A proprietary article, 2 oz. per sq. yd.:—7 dead, 39 moribund, 9 unaffected—ultimately all died, *i.e.*, 13 per cent. killed, 83·6 per cent. dead and affected.

Plot 3.—Naphthalene, 4 oz. per sq. yd.:—63 dead, 9 moribund, 2 unaffected, *i.e.*, 85 per cent. killed, 97·3 per cent. dead and affected.

Plot 4.—Proprietary article, 4 oz. per sq. yd.:—35 dead, 13 moribund, *i.e.*, 73 per cent. killed, 100 per cent. dead and affected.

Plot 5.—Salt, 2 oz. per sq. yd.:—no lethal effect on the grubs apparent.

Plot 6.—Salt, 4 oz. per sq. yd.:—no lethal effect on the grubs apparent, grass severely affected after 1 week.

Plat 7.—Kainit, $1\frac{1}{2}$ oz. per sq. yd.:—no apparent effect on grubs.

Plot 8.—Kainit, 3 oz. per sq. yd.:—no apparent effect on grubs.

Plot 9.—Potash salts, $\frac{3}{4}$ oz. per sq. yd.:—no apparent effect on grubs.

Plot 10.—Potash salts, $1\frac{1}{2}$ oz. per sq. yd.:—no apparent effect on grubs.

Plot 11.—Superphosphate:—no apparent effect on grubs.

Plot 12.—Superphosphate:—no apparent effect on grubs.

As a result of the grass improvement following kainit, already mentioned, $\frac{1}{4}$ acre plots were marked out in a field running from the foot of the fell-side at Crow How Farm, Rydal, and treated in April, 1938, at rates as shown below.

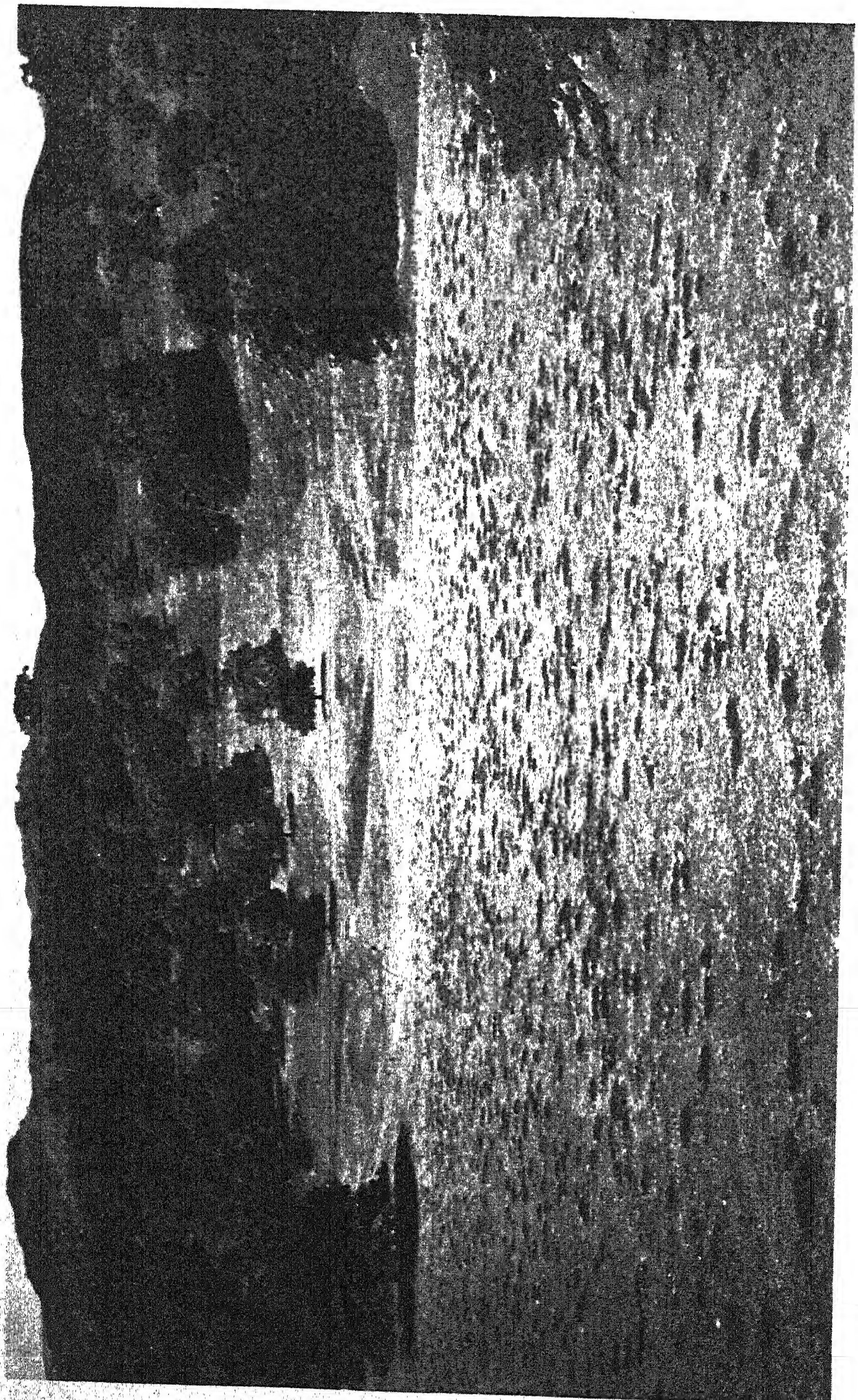
Nitro-chalk top dressing	Nitro-chalk top dressing
Superphosphate	Potash Salts 30%
Potash Salts 30%	Muriate of Potash
Control	Muriate of Potash and Superphosphate
Muriate of Potash	Control
Muriate of Potash and Superphosphate	Superphosphate

Rates of Application.

Superphosphate	...	... ...	6 cwt. per acre
Muriate of Potash	...	... ...	2 cwt. per acre
30% Potash Salts	...	... ...	4 cwt. per acre
Nitro-chalk	...	... ...	3 cwt. per acre

A long period of exceptionally wet weather followed the application of the dressings and much of the manures must have been washed away. Hence, although it was hoped that one or other of the plots would give some indication of grass improvement pointing to control against Chafer grub damage, the observations made by various experts in grass growing who kindly examined the plots from time to time in 1938 and the next two years, were disappointing. No very striking difference in the herbage could be noted between any of the treated and the control plots, although the top quarter acre portions next to the fell-side could with some difficulty be placed in the following order of precedence:—(i) Muriate of potash and superphosphate; (ii) Potash salts; (iii) Superphosphate, and (iv) Muriate of potash, this last plot showing no better than the control plot.

At the same time smaller (1/20 acre) plots, facing south, were marked out—one on a rising part of the field containing the main plots, the other situated some distance up the fell-side. These two sets of plots received the same manurial



A photograph showing the contrast in the herbage where the droppings of stock have fallen.

dressings at the same rate per acre in the following order:—(1) potash salts, (2) potash salts and superphosphate, (3) superphosphate, (4) muriate of potash, (5) muriate of potash and superphosphate. In plot No. 2 in each set the bare patches were raked, as a substitute for harrowing, and reseeded. This plot showed a growth of herbage free from signs of grub attack distinctly superior to that seen in any of the others—an opinion also expressed independently by the farmer. In both these large and small plots the land did not respond to potash so markedly as in the case of the previously mentioned fields. Indeed, a chemical analysis of the grassland at Crow How Farm showed no lack of potash in the soil.

Natural Control.

There is no doubt that birds get rid of large numbers of Chafer beetles and grubs, and some of the older local inhabitants believe that any increase of damage to the hill grassland is due to the small numbers of sea-gulls visiting it as compared with say fifty or sixty years ago. The appearance of gulls is also somewhat erratic. In 1938 for example, fairly large flocks visited the Rydal fells area during the flight period, but in the following year only a few were observed—the largest number being about a dozen, seen feeding on the 15th and 16th of June. During the flight period of the beetle, rooks were also noted devouring large numbers. These latter, together with starlings, also cause much damage to the grass by pulling it out while searching for the grubs underneath.

A certain proportion, estimated at 6·7 per cent. from an examination of about 600 larvae, was affected with a bacterial disease, apparently associated with *Micrococcus nigrofaciens* attacking chiefly the tarsus and claws. A Mermithid worm also occurred to the extent of 0·54 per cent. of larvae examined.

Conclusions and Remarks on Control.

(1) In the improverished fell grassland of the Lake District, judicious manuring may well be considered as a means of helping the grass to " grow away " from attacks even if the manures are innocuous to the grubs. As bearing upon this one might refer to the numerous luxuriant growths of grass in the field at Crow How Farm, where droppings from the stock had previously fallen. Chafer grubs were found plentifully on several of these scattered patches without doing appreciable injury to the grass (Plate IX).

(2) Harrowing and the reseeding of bared patches as well as suitable manuring are to be recommended for the lower or more level areas.

(3) The systematic cutting down of bracken would discourage the settling of the beetles at mating time. Such cutting was begun on 2nd June at Rydal by horse and machine, but it was soon found to be too dangerous for horse and man, to be regarded as practicable, on the steep and often rocky gradients of the fells. Also, the annual treatment necessary for getting rid of bracken would be likely to break down in practice owing to the frequent changes of tenancy in the case of many Lake District fell farms.

(4) It is possible that with the present day developments in insecticides, a dust harmless to stock will be devised for effectually controlling the beetles on a large scale during their comparatively short flight period.

Summary.

1. The Garden Chafer (*Phyllopertha horticola*) causes extensive deterioration of the fell grassland in the Lake District.

2. The flight period of the adult beetles occurs between the end of May and the latter end of June.

3. Eggs are laid in the soil at a depth of about 2½ inches, but the depth varies according to the nature of the soil. The eggs take from 27 to 30 days to hatch in the field.

4. The grub destroys the grass roots and the botanical composition of the grassland deteriorates owing to the colonisation of infested areas by weed growth. Damage is accentuated by the predatory activities of rooks.

5. There is only one generation a year. The fully fed grubs abandon the roots and descend to the subsoil towards the end of October to overwinter, the dormant stage continuing until April. A prepupal stage of short duration is followed by the pupal stage which is reached towards the end of April or early May.

6. The egg stage and hatching mechanism are described and the rate of larval growth is indicated.

7. The distribution of Chafer attack in the Lake District is given; the worst affected areas occur at the head of Lake Ullswater and in the vicinity of Grasmere and Rydal Water.

8. In an infested area, the grubs are often most numerous where the gradient increases. Estimates of the grub population in one locality gave 113,520 grubs per acre on the fell-side and 67,207 per acre on the level portion.

9. The number of grubs per acre is lower when conditions are excessively wet or excessively dry. Most grubs were found where birds were at work on the turf; there were more in dry friable soil than in moist soil and more in places bordering on bracken than in areas at a distance from it.

10. Control by insecticides is impracticable for various reasons.

Damage appears to be less where attempts at grassland improvement have been made. An autumn dressing of basic slag followed by a dressing of kainit the ensuing May is to be recommended and harrowing and reseeding of bared patches for the lower or more level patches are also advised.

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A LABORATORY COMPARISON OF THE TOXICITY AS A CONTACT POISON OF DDT WITH NICOTINE, DERRIS PRODUCTS AND THE PYRETHRINS.

By C. Potter, F. Tattersfield & Mrs. E. M. Gillham.

Introduction.

A considerable amount of work has now been published on the toxicity to insects of the synthetic insecticide DDT (2, 2 bis-parachlorophenyl-1, 1, 1-trichloroethane).

Some laboratory trials have been reported, but these have been made in order to get an estimate of its effect and for the most part there has not been any attempt to make a quantitative comparison of its toxicity with other standard insecticides, although there are some tests of this nature recorded, *e.g.*, in the symposium produced by the Bureau of Entomology and Plant Quarantine, U.S.A. (Annand & others).

The object of the present work was to obtain a quantitative measurement of the toxicity of DDT as a contact poison to a number of species of insects under a standard set of conditions and to compare it with other more commonly used contact insecticides tested under the same conditions. It was hoped that by this means a comparative estimate could be made of the intrinsic contact toxicity of the various insecticides. By intrinsic toxicity is meant the toxicity at the site of action of the poison in the insects.

The various factors operating in the field such as weathering, light intensity, solubility, etc., make it impossible to estimate intrinsic toxicity from field trials so that while these trials are the only criterion for immediate application they do not supply all the knowledge on which to base research and development.

A number of insect species were used, these insects were all common pests of plants, both ornamental and economic.

It is realised that the conditions of the tests, particularly the media employed and the conditions of after-treatment, are likely to affect both the absolute and relative toxicity of the poisons; but the results given here may serve as a useful guide since the comparisons are made where the tests were carried out on the same day and the external conditions were similar. Some data on the effect of media on toxicity are given and the results of a more detailed study will be found in the paper immediately following (Tattersfield *et al.*).

Materials and Method.

Some of the species of test insect were reared and others collected from the field, the details are given in separate sections.

The apparatus and general procedure have already been described (Potter, 1941). Some modifications of procedure were necessary with the different test subjects which are described in the appropriate section. When a warm plate (37-40°C.) (Tattersfield & Potter, 1943) was used in the inspections, a note is made in the text.

The poisons were not always tested or compared in the same medium. The medium now frequently used in this laboratory for comparative tests is a water solution of 0·1 per cent. w/v sulphonated lorol containing 10 per cent. v/v acetone, but the earlier experiments showed that with this medium DDT precipitated out rapidly at the higher concentrations used. The DDT was then tested in a water medium containing 0·1 per cent. w/v sulphonated lorol and 4 per cent. w/v Belloid T.D., and 10 per cent. v/v acetone; this again was not entirely satisfactory.

Finally at the suggestion of Dr. Hubert Martin, of Long Ashton Research Station, the DDT was applied in a water medium containing 0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol and 0·5 per cent. v/v acetone, termed "carbitol basal medium". The technique used for this medium was to make a stock solution of DDT in 25 ml. of acetone, add to 75 ml. of carbitol in which was dissolved 5 gm. of sulphonated lorol T.A. and to dilute measured quantities of this solution for use. The medium was kept constant in composition throughout the range of dilutions by addition of the necessary amounts of the "carbitol basal medium".

This medium also had its drawbacks and a description is given in the paper immediately following (Tattersfield *et al.*) of a comparison of the toxicity of DDT applied in it and in a benzene emulsion, the latter proving more effective.

For the statistical analysis, the method of probits was used (Bliss, 1935) making, where necessary, the adjustments for controls set out by Finney (1944).

Toxicity of DDT and Nicotine to *Aphis* (*Doralis*) *fabae*, Scop.

Insects.—These were reared on *Amaranthus* in a glasshouse, they appeared to be in good condition. The stage used was the adult apterous viviparous parthenogenetic female.

Media.—DDT:—0·1 per cent. w/v sulphonated lorol, 4 per cent. w/v Belloid T.D., 10 per cent. v/v acetone. Nicotine:—0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone.

Procedure.—The insects were taken off the plant on the day of spraying and put in 2 in. × 1 in. glass tubes which were left in the laboratory until treatment. They were transferred to 9 cm. petri dishes containing tricoline for treatment. After treatment, a piece of *Amaranthus* stalk was added and the dish covered with muslin. At the end of spraying all the dishes were taken down to a cool basement and kept there until inspection, which was carried out after 1 and 2 days. Fresh food was added after the first inspection but results were based on the second (on a warm plate at 37-40°C.). The badly affected, moribund and dead were classified as dead. The results are set out in Table I.

TABLE I.

Relative toxicity as contact poisons of DDT and nicotine to *Aphis fabae*.

Concentration %	*Mortality*	*Percentage kill corrected for controls*†
DDT w/v.		
0·1*	44/45	96
0·05*	43/45	93
0·01	33/43	60
Nicotine 95–96% *v/v.*		
0·1	43/43	100
0·05	46/46	100
0·01	37/44	73
Control DDT medium	20/39	
„ Nicotine medium	19/43	
„ Unsprayed	13/44	

* The DDT tended to form crystal aggregates at these concentrations.
† The average of all three controls was used in calculating the corrected percentage kills.

Details of Treatment.

Date of spraying :—13/9/43.
Three replicas each of approximately 15 insects.
Spraying pressure :—42 cms. Hg. Gap $1\frac{7}{10}''$.
Initial temperature :—68°F. Initial relative humidity :—83%.
End temperature :—70°F. End relative humidity :—84%.

Weights of Deposit.

(1) 0·1 sulphonated lorol.
Initial :—9·5 and 9·7 mg./sq.cm. End :—9·5 mg./sq.cm.
(2) 0·1% sulphonated lorol, 4% Belloid T.D.
Initial :—8·9, 9·7 and 9·6 mg./sq.cm. End :—9·5 mg./sq.cm.
Temperature of storage basement :—65°F.

Notes.

There was a high kill in the spray control in the first inspection, 14/ix/43, the unsprayed control showed a mortality of 4/44.
In the second inspection, 15/ix/43, the DDT treated insects showed slight recovery over the first inspection, the nicotine treated showed a slight increase in kill.

Conclusions.—The figures set out in Table I only allow tentative conclusions, particularly since there was a very high mortality in the controls. They indicate that DDT and nicotine in these media and under these conditions are of similar toxicity to this aphid when taken from *Amaranthus*. However, the number killed as apart from those rendered badly affected and moribund was greater with nicotine than with DDT and taking into account all the evidence it seems that nicotine is the better insecticide for this species.

Toxicity of DDT, Nicotine and Rotenone to *Myzus cerasi*, F.

Insects.—These were obtained by collecting infested leaves from cherry trees the day before treatment which were left overnight in the outdoor insectary in a tin with a muslin cover. The stage used was the adult apterous viviparous parthenogenetic female.

Media.—DDT :—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Nicotine and Rotenone :—0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone.

Procedure.—The aphids were transferred from cherry leaves to 2 in. × 1 in. glass tubes with muslin tops on the morning of treatment, 15 insects were put in each tube. The tubes were kept in the laboratory until treatment. The insects were transferred to 9 cm. petri dishes containing a circle of tricoline and sprayed. After treatment, a leaf of wild cherry was added and the dishes were covered with muslin. At the end of a spraying the dishes were taken down to a cool basement (61-62° F. Relative humidity 62-68 per cent. Registered on a recording thermograph and hair hygrograph), where they were kept until inspection.

One detailed inspection was made the day after treatment, using a warm plate. The mortality figures were arrived at by counting the badly affected, moribund and dead, as dead, and the unaffected and slightly affected as alive.

Results.—The results of the experiment are set out in Table II. These results were analysed and the lines derived from the data are set out in fig. 1. The lines for each of the three poisons showed no heterogeneity and no significant departure from parallelism, they were, therefore, plotted as parallel lines and it was possible to make a valid estimate of the relative toxicity based on the L.D. 50. This estimate is set out in Table III.

TABLE II.

Toxicities as contact Poisons of DDT, Nicotine and Rotenone to *Myzus cerasi*.

Concentration %	*Mortality*	*Percentage kill corrected for controls**
DDT in carbitol medium w/v.		
0·1	42/44	94
0·05	41/42	97
0·025	36/45	74
0·0125	28/45	51
0·00625	24/45	40
0·003125	13/41	12
	x = log. (10^5 x conc.) Equation to the probit line adjusted for parallelism. $Y = -1\cdot92 + 2\cdot27$ x.	
Nicotine (95–96%) *in* 10% *acetone medium.*		
0·1	44/44	100
0·05	38/45	82
0·025	30/43	64
0·0125	13/41	19
0·00625	12/41	16
0·003125	9/44	6
	x = log. (10^5 x conc.) Equation to the probit line adjusted to parallelism. $Y = -2\cdot47 + 2\cdot27$ x.	
Rotenone in 10% *acetone medium.*		
0·001	40/40	100
0·0005	32/38	81
0·00025	21/39	45
0·000125	17/41	31
0·0000625	11/45	10
0·00003125	6/39	0
	x = log. (10^5 x conc.) Equation to the probit line adjusted to parallelism. $Y = 1\cdot98 + 2\cdot27$ x.	
Control 10% acetone medium	5/32	
Control carbitol medium	10/44	
Control untreated	6/57	

* Controls for DDT series were taken as control carbitol medium. Controls for nicotine and rotenone were taken as control 10% acetone medium.

Details of Treatment.

Date of spraying:—9/6/44.
3 replicas each of approximately 15 insects.
Spraying pressure:—37·8 cms. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature:—65°F. Initial relative humidity:—84%.
End temperature:—66°F. End relative humidity:—80%.

Weights of Deposit. 10% Acetone medium.

Initial:—Not measured. End:—6·65, 6·35, 6·50 mg./sq.cm.

Carbitol medium.

Initial:—7·60, 7·46 mg./sq.cm. End:—8·14, 8·25 mg./sq.cm.

Discussion of Results.—From these results it would be judged that when acting as a contact poison Rotenone is much more toxic than either DDT or nicotine to the adult apterous viviparous parthenogenetic females of the Cherry Black Fly, *Myzus cerasi*, F. DDT appears to be somewhat more toxic than nicotine but the amount of live reproduction that occurred with the DDT-treated insects indicated that it was not likely to prove satisfactory in practice.

TABLE III.
Relative Potencies of DDT, Nicotine and Rotenone to *Myzus cerasi*.

Insecticide and Medium	m 50	SE ±	Antilog $\frac{m\ 50}{10^5}$ (LD 50)	Relative potency
Nicotine in 10% acetone medium	3·2907	0·053	0·01953	1·0
DDT in carbitol medium ...	3·0485	0·056	0·01118	1·75
Rotenone in 10% acetone medium	1·3304	0·055	0·000214	91·26

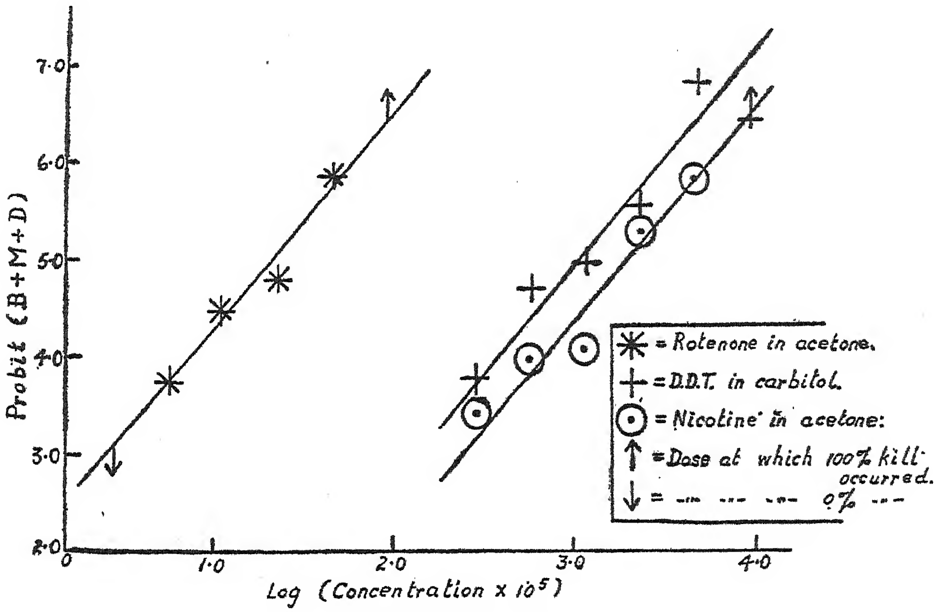

FIG. 1.—*Myzus cerasi* (Cherry Black Fly).

Toxicity of DDT, Nicotine and Rotenone to Adult *Phaedon cochleariae*, F.

Two experiments were made. The results of both are grouped together for the purpose of drawing conclusions.

Experiment 1.

Insects.—These were collected from water-cress beds that had dried up owing to drought. They were collected on the afternoon of the day before treatment and put on mustard in an outdoor insectary overnight.

Media.—DDT:—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Nicotine and Rotenone:—0·1 per cent. sulphonated lorol, 10 per cent. v/v acetone.

Procedure.—The beetles were taken off the mustard on the morning of treatment and put into 2 in. × 1 in. glass tubes, 10 insects per tube. They were kept in the laboratory until treated. The insects were transferred from the tubes to 9 cm. petri dishes containing a circle of tricoline for treatment. Afterwards the dishes were

covered with muslin, and at the end of the spraying the dishes were taken from the laboratory to a cool basement where they were kept. On the day after treatment mustard was added and this food was added subsequently as required.

One detailed inspection was made on the third day after treatment, using a warm plate. The mortality figures were arrived at by counting the badly affected, moribund and dead as dead, and the unaffected and slightly affected as live. The majority of the insects showed a clear-cut division between live and dead by the date of inspection. The results are shown in Table IV.

TABLE IV.

Toxicities as contact poisons of DDT, Nicotine and Rotenone to adult *Phaedon cochleariae*.

Concentration %	*Mortality*	*Percentage kill corrected for controls**
DDT in carbitol medium w/v		
0·2	29/29	100
0·1	30/30	100
0·05	30/30	100
0·025	30/30	100
0·0125	28/29	96
0·00625	29/30	96
Nicotine (95–96%) *in* 10% *acetone medium v/v*		
0·5	30/30	100
0·375	30/30	100
0·25	28/30	93
0·125	23/30	75
0·0625	15/30	46
0·03125	8/29	22
Rotenone in 10% *acetone medium w/v*		
0·01	30/30	100
0·005	28/30	93
0·0025	27/30	89
0·00125	23/30	75
0·000625	12/28	39
0·0003125	11/31	31
$x = \log. (10^4 \times \text{conc.})$ Equation to the probit line $Y = 3{\cdot}64 + 1{\cdot}69\,x$.		
Control 10% acetone medium	0/28*	
Control carbitol medium	5/30*	
Control unsprayed	1/29*	

* The average of the three controls was used in calculating the corrected % kills.

Details of Treatment.

Date of spraying :—2/8/44.
Three replicas each of approximately 10 insects.
Spraying pressure :—25·6 cms. Hg. Gap $1\frac{7}{10}$".
Initial temperature :—74°F. Initial relative humidity :—72%.
End temperature :—77°F. End relative humidity :—70%.

Weights of Deposits.

10% acetone medium.	Initial :—7·2 and 7·4 mg./sq.cm. End :—7·8 and 7·8 mg./sq.cm.
Carbitol medium.	Initial :—6·4 mg./sq.cm. [Nozzle probably partially blocked]. End :—9·4 and 9·4 mg./sq.cm.

Temperature of storage basement immediately after spraying = 66°F.
Relative humidity of storage basement immediately after spraying = 74%.
Storage temperature :—64–65°F. R.H. 72–74%.

Experiment 2.

Insects.—These were collected from brussels sprouts where they had migrated from a dried-up water-cress bed. The insects were kept on mustard in an outdoor insectary until the day of treatment.

Medium.—DDT and Rotenone:—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol and 0·5 per cent. v/v acetone.

Procedure.—This was in general as in Experiment 1.

One detailed inspection was made four days after treatment using the warm plate. The mortality figures were assessed in the same way as in Experiment 1. Again the results were for the most part clear cut, the insects being either alive or dead on the date of inspection.

Results of Experiment 2.

These are set out in Table V.

TABLE V.

Toxicities as contact poisons of DDT and Rotenone to adult *Phaedon cochleariae.*

Concentration %	*Mortality*	*Percentage kill corrected for controls**
DDT in carbitol medium w/v.		
0·0125	25/30	83
0·00625	21/29	71
0·0031	20/39	50
0·00156	4/39	7
0·00078	4/40	7
0·00039	1/38	0
0·00019	1/38	0
	$x = \log. (10^4 \times \text{conc.})$ Equation to probit line $Y = 1·41 + 2·24\,x$.	
Rotenone in carbitol medium w/v.		
0·01	27/28	96
0·005	30/30	100
0·0025	33/40	82
0·00125	19/40	46
0·00062	3/38	5
0·00031	3/39	4
0·00016	0/39	0
	$x = \log. (10^4 \times \text{conc.})$ Equation to probit line $Y = 1·38 + 3·13\,x$.	
Control carbitol medium	3/39*	
Control unsprayed	0/48*	

* The average of the two controls was used in calculating the corrected % kills.

Details of Treatment.

Date of spraying:—8/8/44.
Three replicas each of approximately 10 insects.
Spraying pressure:—not recorded. Gap $1\frac{7}{10}''$.
Initial temperature:—77°F. Initial relative humidity:—56%.
End temperature:—80°F. End relative humidity:—50%.

Weights of deposit, etc.

Carbitol medium. Initial:—7·7 and 7·8 mg./sq. cm.
End:—7·7 and 7·9 mg./sq. cm.

Temperature of storage basement immediately after spraying = 65°F.
Relative humidity of basement immediately after spraying = 67%.
Storage temperature 64–65°F. R.H. 70–78%. (Registered on a recording thermograph and recording hair hygrograph.)

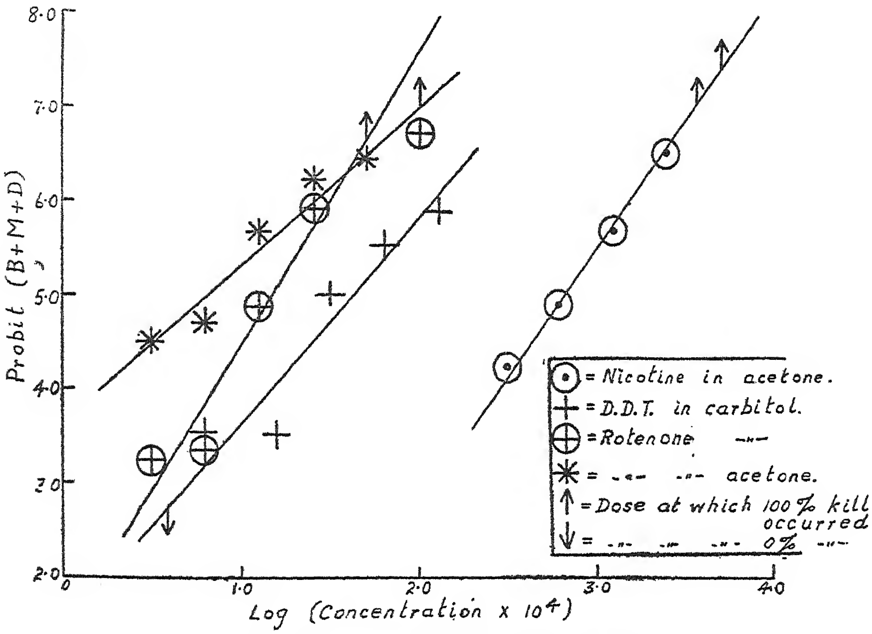

FIG. 2.—*Phaedon cochleariae* (Mustard beetle).

Results of Experiments 1 *and* 2.

The results of both experiments were analysed separately, but the lines derived from the data are shown on a single graph (fig. 2), and for the purpose of working out the relative toxicity between the poisons the data were treated as if they had been obtained in a single experiment; the results of the assessment of relative toxicity are shown in Table VI.

The equations to the lines are given in Table IV and V except in the DDT Experiment 1, where the concentrations were too high and no range of mortality was obtained. There was no heterogeneity in any of the data. Tests for significance indicated that the lines for the toxicity of the various poisons could not be constrained to parallelism, a comparison of toxicity at L.D. 50 does not, therefore, provide an adequate index. The relative toxicities were, therefore, measured at the L.D. 75, L.D. 50 and L.D. 25, these are set out in Table VI.

TABLE VI.

Relative potencies of Nicotine, DDT and Rotenone to *Phaedon cochleariae*. Experiments 1 and 2.

Insecticides and medium	(m) 75	S.E.±	Antilog $\frac{m\ 75}{10^4}$ =L.D.75	Relative potencies
Nicotine in acetone v/v	3·0640	0·049	0·1159	1·0
DDT in carbitol w/v	1·9033	0·077	0·00800	14·5
Rotenone in carbitol w/v	1·3734	0·041	0·00236	49·1
Rotenone in acetone w/v	1·2072	0·077	0·0016	72·4

Insecticides and medium	(m) 50	S.E.±	Antilog $\frac{m\ 50}{10^4}$ =L.D.50	Relative potencies
Nicotine in acetone v/v	2·8181	0·054	0·0658	1·0
DDT in carbitol w/v	1·6022	0·055	0·0040	16·4
Rotenone in carbitol w/v	1·1577	0·039	0·0014	47·0
Rotenone in acetone w/v	0·8074	0·086	0·0006	109·7

Insecticides and medium	(m) 25	S.E.±	Antilog $\frac{m\ 25}{10^4}$ =L.D.25	Relative potencies
Nicotine in acetone v/v	2·5723	0·075	0·0374	1·0
DDT in carbitol w/v	1·3011	0·061	0·0020	18·7
Rotenone in carbitol w/v	0·9420	0·051	0·0009	41·6
Rotenone in acetone w/v	0·4075	0·135	0·0003	124·7

Discussion of Results.

Even taking into account the lack of parallelism, the results indicate that with this insect under the experimental conditions described, rotenone in either a 10 per cent. acetone medium or in carbitol medium is more toxic, weight for weight, than DDT in the " carbitol medium " and that both of these are much more toxic than nicotine in acetone medium. It appears also from these experiments that with this insect the change in toxicity of rotenone with concentration depends upon the medium with which it is incorporated.

Toxicity of DDT and Nicotine to the Larvae of *Cheimatobia brumata*, L.

Two experiments were made on the larvae of the winter moth, the first a preliminary test on the effect of DDT and the second of DDT and nicotine.

Experiment 1.

Insects.—The larvae were collected during the week before the experiment and kept on hawthorn in the outdoor insectary. The insects were taken from several host plants, but mostly from apple.

The majority of the larvae were fully grown or nearly fully grown.

Medium.—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone.

Procedure.—The larvae were taken off their food on the morning of treatment and put in 2 in. × 1 in. glass tubes, 10 insects per tube, in the afternoon. They were transferred from the tubes to 9 cm. petri dishes containing a circle of tricoline for treatment. After treatment the dishes were covered with muslin and at the end of the spraying were taken from the laboratory to a cool basement and kept there.

The day after treatment the insects and tricoline circles were removed from the petri dishes and put in deep crystallising dishes, 7 cm. in diameter, which had approximately ¾ in. powdered peat saturated with water on the bottom. Each

dish was covered with the muslin used for the corresponding petri dish. Hawthorn foliage as food was then added to the dishes. Food was subsequently added at intervals as required.

Two detailed inspections were made five and twelve days after spraying. By the latter date, all except one of the controls had pupated in the peat, the conditions provided seemed thus to be quite favourable to the insects and there was no mortality at all in the controls. Mortality was assessed by adding up the dead larvae found in two inspections and expressing this as a fraction of the total insects. The results of experiment 1 are shown in Table VII.

TABLE VII.

Toxicity of DDT as a contact poison to fully grown or nearly fully grown larvae of *Cheimatobia brumata*.

Concentration % DDT in carbitol medium w/v.	*Mortality*	*Percentage kill*
0·1	30/30	100
0·05	30/30	100
0·025	30/33	91
Control carbitol medium	0/20	
Control unsprayed	0/10	

By 7 p.m. on the day after treatment all the controls were perfectly normal, whereas all the insects sprayed with DDT were badly affected and incapable of crawling. Many were shrivelling and turning brown although very few appeared to be dead. Most of the treated larvae exhibited a marked twitching movement.

Details of Treatment.

Date of spraying:—18/5/44.
Three replicas each of 10 insects approximately for the concentrations of DDT.
Two replicas each of 10 insects for the concentrations of carbitol control.
Two replicas each of five insects for the unsprayed control.
Spraying pressure:—37·7 cms. Hg. Gap $1\frac{7}{10}''$.
Initial temperature:—56°F. Initial relative humidity:—75%.
End temperature:—56°F. End relative humidity:—75%.

Weights of deposits, etc.

Initial:—7·6 mg./sq. cm. End:—7·3 mg./sq. cm.
Temperature of the storage basement immediately after spraying = 56°F.
Relative humidity of the storage basement immediately after spraying = 58%.

Experiment 2.

Insects.—These were collected from apple trees during the week before treatment and kept before spraying on hawthorn in an outdoor insectary. On the second collection some of the insects in the field appeared to be diseased and again when they were being selected for treatment some of the smaller ones were rejected for the same reason. The insects were from $\frac{1}{3}$rd to fully grown.

Medium.—0·1 per cent. sulphonated lorol w/v T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone.

Procedure.—As in Experiment 1. The inspection and method of assessment of results were as follows:—

Detailed inspections were made on the first, sixth, nineteenth and thirtieth days. The fourth and final inspection took the form of going through the peat to find how many cocoons were present. The cocoons were difficult to find in the peat and the figures were not thought to be reliable; the mortality figures are, therefore, derived from the first three inspections. If the results of the fourth inspection were included there would have been a considerably greater overall mortality but the relative results would be much the same, the figures as shown are thought to be a fair index of the toxicity of the compounds. The figures are made up by expressing the dead insects found in the first three inspections as a ratio of the total insects treated.

Results.—Results of Experiment 2 are shown in Table VIII and graphically in fig. 3.

TABLE VIII.

Toxicities of DDT and Nicotine to ⅓ to fully grown larvae of *Cheimatobia brumata*.

Concentration %	*Mortality*	*Percentage kill corrected for controls**
DDT in carbitol medium w/v		
0·025	28/32	86
0·01	34/39	86
0·005	25/38	63
0·0025	8/29	21
	x = log. (10^4 x conc.)	
	Equation to the probit line adjusted for parallelism	
	Y = 2·11 + 1·81 x.	
Nicotine (95–96%) *in carbitol medium v/v*		
0·5	20/31	61
0·25	15/40	32
0·125	17/40	37
0·0625	4/30	6
	x = log. (10^4 x conc.)	
	Equation to the probit line adjusted for parallelism	
	Y = − 1·35 + 1·81 x.	
Control carbitol medium	3/29*	
Control unsprayed	2/33*	

* The average of the two controls was used in calculating the corrected % kills.

Details of treatment.

Date of spraying :—25/5/44.
Three or four replicas each of approximately 10 insects.
Spraying pressure :—48·6 cm. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature :—62·5°F. Initial relative humidity :—70%.
End temperature :—63·5°F. End relative humidity :—71%.

Weights of deposit, etc.

Initial :—7·2, 7·1, 7·3 mg./sq. cm.
End :—6·4, 6·6, 6·7 mg./sq. cm.
Temperature of storage basement immediately after spraying = 60°F.
Relative humidity of storage basement immediately after spraying = 74%.

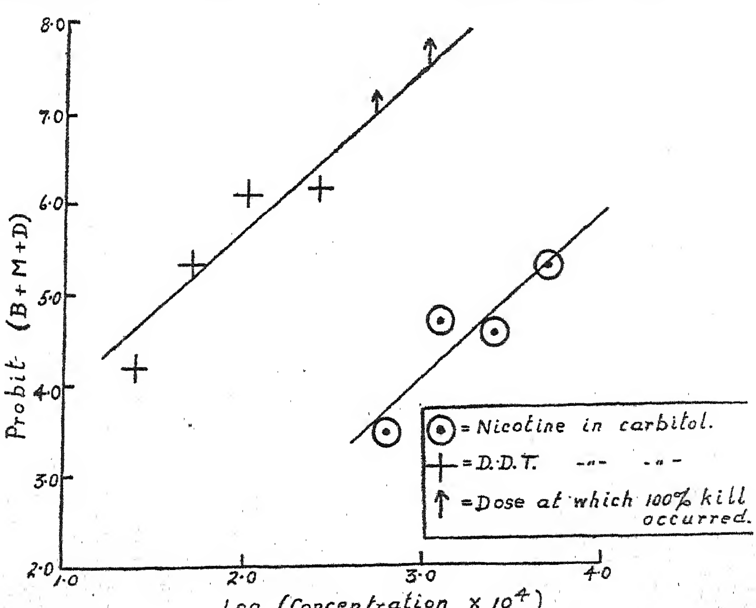

FIG. 3.—*Cheimatobia brumata* (Winter moth).

Results of Experiments 1 *and* 2.

A statistical analysis was made of the data. For the purpose of analysis the toxicity figures for DDT in the first experiment were added to those of the second experiment; the controls of the second experiment were used for correction purposes.

No heterogeneity was found in the data, and they were adequately fitted by parallel lines, which are shown in fig. 3. Since the lines were parallel a comparison of the toxicity at the L.D. 50 was made. This is shown in Table IX, from which it will be seen that, under the conditions of the experiment, DDT was much more toxic than nicotine to the larvae of this species. DDT is measured as w/v and nicotine as v/v, but assuming the specific gravity of nicotine to be 1·01 the difference made by this would be insignificant.

TABLE IX.

Relative potency of DDT and Nicotine to the larvae (1/3 to fully grown) of *Cheimatobia brumata*.

Poison and medium	(m) 50	SE ±	LD 50 (antilog m50/10⁴)	Relative potency
Nicotine in carbitol	3·5083	0·083	0·322	1·0
DDT in carbitol	1·5967	0·084	0·004	80·6

Experiment on the Toxicity of DDT and Nicotine to the Larvae of *Hyponomeuta cognatella*, Hb.

Insects.—The larvae were collected from *Euonymus* on the morning of spraying; they were for the most part fully grown or nearly fully grown.

Medium.—DDT and Nicotine:—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol and 0·5 per cent. v/v acetone.

Procedure.—The larvae were collected and sorted in the morning into 2 in. × 1 in. glass tubes, 10 in each tube, and kept in the laboratory until treated. The larvae were transferred to 9 cm. petri dishes containing tricoline for treatment. Afterwards, the dishes were covered with muslin. At the end of the spraying all the dishes were taken to a cool basement and left. Food was added the following day and subsequently at intervals as required.

Two detailed inspections were made on the first and ninth day after treatment. The mortality figures were derived by adding together the dead and moribund insects found in the two inspections and expressing these as a fraction of the total number at the beginning of the experiment. At the time of the last inspection about half of the surviving larvae had pupated. The results are set out in Table X.

TABLE X.

Relative toxicity as contact insecticides of DDT and Nicotine to larvae of *Hyponomeuta cognatella*, Hb.

Concentration %	*Mortality*	*Percentage kill corrected for controls**
DDT in carbitol medium w/v.		
0·05	16/39	39
0·025	7/41	15
0·01	0/38	0
0·005	1/40	0
0·0025	1/39	0

* The average of the two controls was used in calculating the corrected % kills.

Nicotine in carbitol medium v/v.		
0·5	17/46	35
0·25	12/39	29
0·125	6/44	11
0·0625	2/41	2
Control carbitol medium	2/27*	
Control unsprayed	0/44*	

* The average of the two controls was used in calculating the corrected % kills.

Details of Treatment.
Date of spraying:—30/5/44.
4 replicas each of approximately 10 insects.
Spraying pressure: 46·4 cms. Hg. Gap $1\frac{7}{10}''$.
Initial temperature:—79°F. Initial relative humidity:—65%.
End temperature:—82°F. End relative humidity:—65%.

Weights of deposit, etc. Carbitol medium.
Initial:—6·9 mg./sq. cm. End: 6·4 mg./sq. cm.
Temperature of storage basement immediately after spraying = 64·4°F.
Relative humidity of storage basement immediately after spraying = 75%.

Discussion of results.—The results are not worth statistical treatment but they indicate that the fully grown larvae of this species are resistant to both DDT and nicotine.

Experiments on the Toxicity of DDT, Nicotine, Derris Products and the Pyrethrins to the fully grown Larvae of *Pieris brassicae*, L.

Two experiments were carried out. These are described separately but the results are treated together since they are complementary. The following are the details.

Insects.—The high degree of parasitism occurring with specimens of larvae of this species, collected in the field, rendered it necessary to use laboratory-reared material. For these experiments, therefore, butterflies were caught on the wing and allowed to lay eggs in cages in a glasshouse and the larvae for the tests were reared from these eggs on cabbages kept under muslin cages inside a glasshouse.

Very little evidence of either parasitism or disease was found in the cultures. Of the 661 insects used for the two tests only three larvae were parasitised and two died of what appeared to be disease. A few specimens turned black and died after pupation; indicating the possibility of pupal infection. Thus the insects as a whole appeared to be in very good condition. The fully grown larvae were used in the tests.

Media.—DDT, experiments (1) and (2):—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Nicotine, experiments (1) and (2):—0·1 per cent. w/v sulphonated lorol T.A., 10 per cent. v/v acetone. Rotenone, experiment (2):—0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone. *Derris elliptica*, resin W.216:—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Pyrethrins, experiment (1):—0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone. Pyrethrins, experiment (2):—0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone.

Procedure.—The insects were removed from their food in the morning and kept in the laboratory in 9 cm. petri dishes, five larvae per dish, until treated later in the day. The dishes were kept in the laboratory until treated. Immediately prior to treatment the larvae were removed, a circle of tricoline placed in the bottom of each dish, the larvae replaced and sprayed and the dish was then covered with muslin. At the end of the spraying the dishes were taken to a cool basement.

No food was added at the time of treatment but cabbage leaves were added the following day and at later intervals, where necessary, during the period of inspection.

Inspection and Method of Assessment of Results.—Four detailed inspections of the larvae treated on 30/8/44 were made on the fourth, seventh, fourteenth and nineteenth day after treatment. Four detailed inspections were also made of the larvae treated on 5/9/44. These took place on the seventh, ninth, thirteenth and fourteenth day after treatment. All the larvae in both treatments had pupated or died before the last inspection. The criterion of survival was the formation of a normal pupa which was alive at the last inspection.

It was noteworthy that a very different estimate would have been obtained if the larval death rate was used as a basis, since in very many instances the insects died at various stages in the metamorphosis from larva to pupa.

The assessment of the results of the effect of DDT was the most straightforward. It appeared that larvae, sufficiently affected to die, subsequently stopped feeding and began to shrivel after treatment, the insects were nearly all killed as larvae. If they survived they became apparently normal pupae.

The pyrethrins also killed in the larval stage a high proportion of the insects, but some went on to form abnormal prepupae and pupae before death occurred.

With the derris products and nicotine a high proportion of the insects survived as apparently normal larvae until pupation, when abnormal prepupae and pupae were formed which ultimately died. Deformation and death occurred at various stages in the formation of the prepupae and pupae. Typical of the early stages was the production of a prepupa with an elongated abdomen. Probably the most prevalent stage in which development was arrested and death intervened was after the dorsal cap of the thoracic shield of the pupa had been formed, but in some instances the complete head, thorax and wing covers were formed but the abdomen remained in the prepupal state.

Table XI shows the result of the inspection, each set of mortality figures being set out under the dates on which the insects concerned were treated. For the statistical analysis of the results the figures were regarded as if the treatment on both dates were a single experiment. It is thought that this was permissible in this instance since the conditions of treatment were similar, but the results have not the same significance as if they had been obtained in a single experiment.

TABLE XI.

Toxicities of DDT, Derris Resin W 216, Rotenone, Nicotine and the Pyrethrins to fully grown larvae of *Pieris brassicae*.

Results of experiments 1 and 2.

Experiment 1

(a) DDT in carbitol medium			(b) Derris resin W 216 in carbitol medium		
Concentration % w/v	Mortality	Corrected % kill	Concentration % w/v	Mortality	Corrected % kill
0·10	15/15	100	0·20	14/15	93
0·05	9/15	59	0·10	11/15	72
0·025	4/15	24	0·05	8/15	52
0·0125	2/20	7	0·025	6/14	41
0·0062	2/14	11	0·0125	1/14	4
0·0031	3/13	20*	0·0062	2/15	10

* Point omitted from calculations.

(c) Nicotine in 10% acetone medium			(d) †Pyrethrins I and II in 10% acetone medium		
Concentration % v/v	Mortality	Corrected % kill	Concentration % w/v	Mortality	Corrected % kill
1·0	15/15	100	0·015	9/15	59
0·5	9/15	59	0·0058	6/15	38
0·25	7/14	48	0·0029	2/15	10
0·125	5/15	31	0·0014	1/15	3
0·0625	4/14	26	0·0007	3/14	19*

	Mortality
Control 10% acetone medium ...	1/15
Control carbitol medium	0/14

* Point omitted from calculations

Experiment 2

(a) DDT in carbitol medium			(b) † Pyrethrins I and II in carbitol medium		
Concentration % w/v	Mortality	Corrected % kill	Concentration % w/v	Mortality	Corrected % kill
0·10	20/20	100	0·115	18/19	95
0·075	19/20	95	0·058	20/20	100
0·05	12/20	59	0·029	17/20	84
0·025	3/20	12	0·014	13/20	64
0·0125	3/20	12	0·007	8/20	38
			0·0036	1/18	2

(c) Derris resin W 216 in carbitol medium			(d) Rotenone in 10% acetone medium		
Concentration % w/v	Mortality	Corrected % kill	Concentration % w/v	Mortality	Corrected % kill
0·4	14/14	100	0·1	10/15	66

(e) Nicotine in 10% acetone medium.

Concentration % v/v	Mortality	Corrected % kill
4·0	15/15	100
2·0	14/14	100

	Mortality
Control 10% acetone medium ...	0/15
Control carbitol medium	1/15

† The pyrethrins were made up from a stock solution containing 1·4 parts pyrethrin I to 1 part pyrethrin II by weight. Pyrethrin I was estimated by Martin and Brightwell's modification of the Wilcoxon-Holiday method (1 cc. M/100 KIO_3 = 5·8 mg. pyrethrin I). Pyrethrin II was estimated by Martin and Brightwell's modification of Seil's method.

Notes to Table XI.

The average of all four controls was used in calculating corrected percentage kills.

Details of Treatment. Experiment 1.

Date of spraying :—30/8/44.
Three replicas each of 5 insects.
Spraying pressure :—33·6 cm. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature :—71°F. Initial relative humidity :—57%.
End temperature :—74°F. End relative humidity :—55%.

Weights of deposit, etc.

10% acetone medium :—Initial :—6·9 mg./sq. cm. End :—7·2, 7·2 mg./sq. cm.
Carbitol medium :—Initial :—not measured. End :—9·2, 9·1 mg./sq. cm.
Temperature of storage basement immediately after treatment = 67°F.
Relative humidity of storage basement immediately after treatment = 62%. (Whirling hygrometer.)

Experiment 2.

Date of spraying :—5/9/44.
From 3 to 4 replicas each of five insects.
Spraying pressure :—34·6 cms. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature :—66°F. Initial relative humidity :—64%.
End temperature :—66°F. End relative humidity :—60%.

Weights of deposits, etc.

Acetone medium :—Initial :—6·7, 7·2 mg./sq. cm. End :—6·9 mg./sp. cm.
Carbitol medium :—Initial :—9·0, 9·2 mg./sq. cm. End :—8·5, 9·0, 8·9 mg./sq. cm.
Temperature of storage basement immediately after spraying :—64°F.
Relative humidity of storage basement immediately after spraying :—65%. (Whirling hygrometer.)

TABLE XII.

Toxicities of various poisons to the larvae of *Pieris brassicae*.

Experiments 1 and 2.

Combined data from the probit calculations.

(a) DDT in carbitol medium			(b) Derris resin W.216 in carbitol medium		
Concentration % w/v	Mortality	Corrected % kill	Concentration % w/v	Mortality	Corrected % kill
0·1	35/35	100	0·4	14/14	100
0·075	19/20	95	0·2	14/15	93
0·05	21/35	59	0·1	11/15	72
0·025	7/35	17	0·05	8/15	52
0·0125	5/40	9	0·025	6/14	41
0·0062	2/14	11	0·0125	1/14	4
0·0031	3/13	20*	0·0062	2/15	10

* Point omitted from calculation.

(a) $x = \log.(10^3 \times \text{conc.})$
Equation to the probit line
$Y = -0{\cdot}29 + 3{\cdot}38\,x$.

(b) $x = \log.(10^3 \times \text{conc.})$
Equation to the probit line
$Y = 1{\cdot}82 + 1{\cdot}95\,x$.

(c) Nicotine in acetone medium

Concentration % v/v	Mortality	Corrected % kill
4·0	15/15	100
2·0	14/14	100
1·0	15/15	100
0·5	9/15	59
0·25	7/14	48
0·125	5/15	31
0·0625	4/14	26

x = log. (10^3 x conc.)
Equation to the probit line
Y = 1·33 + 1·56 x.

(d) Pyrethrins I and II in carbitol medium

Concentration % w/v	Mortality	Corrected % kill
0·115	18/19	95
0·058	20/20	100
0·029	17/20	84
0·014	13/20	64
0·007	8/20	38
0·0036	1/18	2

x = log. (10^3 x conc.)
Equation to the probit line
Y = 2·51 + 2·39 x.

(e) Pyrethrins I and II in acetone medium

Concentration % w/v	Mortality	Corrected % kill
0·0115	9/15	59
0·0058	6/15	38
0·0029	2/15	10
0·0014	1/15	3
0·0007	3/14	19*

(f) Rotenone in acetone medium

Concentration % w/v	Mortality	Corrected % kill
0·1	10/15	66
Controls	2/59	

* Point omitted from calculation.

x = log. (10^3 x conc.)
Equation to the probit line
Y = 2·75 + 2·39 x.

The controls in both acetone and carbitol medium were added and the total used for the calculation of the corrected percentage killed.

Results.—The combined figures were analysed, the data throughout showed no heterogeneity when the two obviously aberrant points, marked with an asterisk, were omitted.

The equations to the lines of the combined results are given in the table (Table XII) and the lines themselves are shown in the graph (fig. 4). The difference between the toxicities of all the four poisons are significant but there is no significant difference between the pyrethrins in 10 per cent. acetone medium and the pyrethrins in carbitol.

Tests for significance indicate that the lines for the toxicity of the various poisons cannot be constrained to parallelism, a comparison of toxicity at L.D. 50 does not, therefore, provide an adequate index. Comparisons were, consequently, made at L.D. 75, L.D. 50 and L.D. 25. These are set out in Table XIII.

Discussion of Results.—Judging from these data, it may be seen that the relative toxicity between any of the poisons dealt with will depend on the mortality level at which it is assessed, since the toxicity curves are not parallel. The reliability of the data is not great since the number of insects used is not large, but if the aberrant figures for the lowest concentrations of DDT and the pyrethrins are excluded no heterogeneity is apparent.

TABLE XIII.

Relative potencies as contact poisons of Nicotine, DDT, Derris resin W.216, and the Pyrethrins to the fully grown larvae of *Pieris brassicae.*

Insecticide and Medium	(m) 75	S.E. ±	Antilog. $m75/10^3$ = L.D.75	Relative potency
Nicotine in acetone	2·7839	0·091	0·6080	1·0
Derris elliptica in carbitol	1·9767	0·088	0·0948	6·4
DDT in carbitol	1·7621	0·038	0·0578	10·5
Pyrethrins in carbitol	1·3281	0·066	0·0213	28·5
Pyrethrins in acetone	1·2233	0·165	0·0167	36·4

Insecticide and Medium	(m) 50	S.E. ±	Antilog. $m50/10^3$ = L.D.50	Relative potency
Nicotine in acetone	2·3521	0·032	0·2250	1·0
Derris elliptica in carbitol	1·6311	0·078	0·0428	5·3
DDT in carbitol	1·5627	0·033	0·0365	6·2
Pyrethrins in carbitol	1·0453	0·065	0·0111	20·3
Pyrethrins in acetone	0·9410	0·101	0·0087	25·9

Insecticide and Medium	(m) 25	S.E. ±	Antilog. $m25/10^3$ = L.D.25	Relative potency
Nicotine in acetone	1·9203	0·146	0·0832	1·0
Derris elliptica in carbitol	1·2856	0·099	0·0193	4·3
DDT in carbitol	1·3632	0·042	0·0231	3·6
Pyrethrins in carbitol	0·7625	0·088	0·0058	14·3
Pyrethrins in acetone	0·6586	0·093	0·0046	18·1

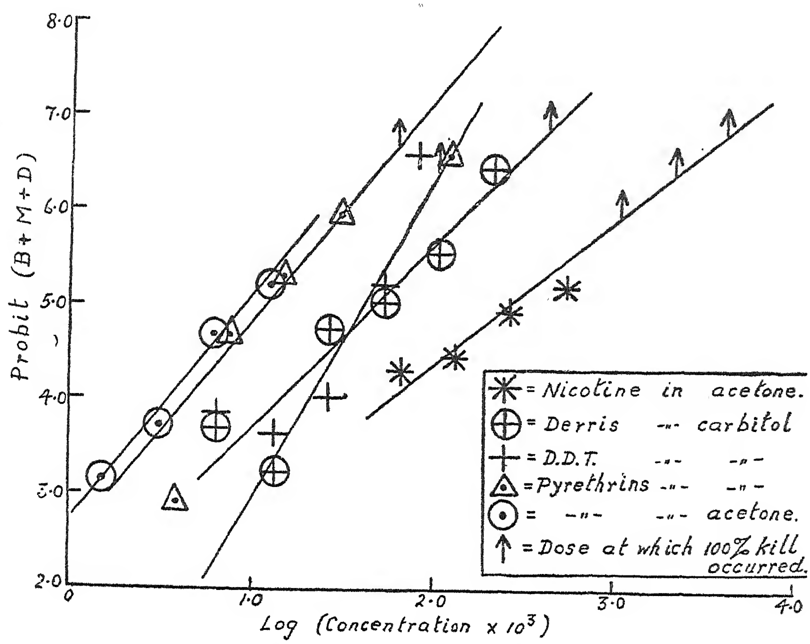

FIG. 4.—*Pieris brassicae* (Cabbage White butterfly).

Even if large margins of error are assumed, the general features appear to be that the pyrethrins either in acetone or carbitol medium are most toxic, having at least three times the potency of DDT in carbitol medium.

DDT and Derris resin W.216, both in carbitol, are of the same order of toxicity at the 50 per cent. kill point and at lower kills but the DDT is much more toxic at the higher percentage kills. The difference at the higher mortalities may be influenced by the rate of aggregation of the derris product, and it is interesting to note that the figures obtained indicate that the derris resin, containing 37-40 per cent. rotenone, at 0·1 per cent. in carbitol is of the same order of toxicity as 0·1 per cent. pure rotenone in acetone. Nicotine in acetone is much less toxic than any of the other poisons used and the difference is most marked at higher kills, nor would this difference be significantly reduced if the nicotine concentrations were expressed on a w/v basis as are the other three.

Experiments on the Toxicity of DDT, Nicotine, Rotenone and the Pyrethrins to the Larvae of *Pteronus ribesii*, Curtis.

A single test was made on the larvae of this species.

Insects.—The larvae were collected from gooseberry bushes over a period of three days, and kept on gooseberry foliage in an outdoor insectary until the morning of treatment. The larvae were all in the penultimate stage; as far as could be judged no final instar larvae were used.

Media.—DDT 0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Nicotine, rotenone, pyrethrins, 0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone.

Procedure.—On the morning of treatment the larvae were taken off the foliage and put into 2 in. × 1 in. glass tubes, 10 insects in each tube, and kept in the laboratory. The insects were transferred for treatment from the tubes to 9 cm. petri dishes containing a circle of tricoline and sprayed. In the absence of any previous experience, after treatment the dishes were covered with muslin, and at the completion of spraying, were taken down to a cool basement and kept there for four days, after which they were transferred to a constant temperature, constant humidity chamber at 75° F. and 90 per cent. R.H. No food was added until the morning after treatment; subsequently additional food was given as required.

Inspection and Method of Assessment of Results.

Four detailed examinations were made on the first, fourth, seventh, twenty-second and thirty-sixth day after treatment. The assessment of mortality was made on the first two inspections, since after these, natural mortality occurred due to lack of a suitable environment for the larvae to spin cocoons. Cocoon formation did occur on the dish but many of the cocoons were incomplete.

The mortality figures were determined by counting as alive all the insects classified as living larvae, affected larvae and cocoons, and counting as dead all the insects classified as dead and moribund larvae.

It appeared, however, that the larvae which normally formed cocoons in the soil only do so with difficulty in the dishes and that, as a result, some natural mortality occurred after they had been kept for some time; this might not have been so pronounced if the insects had been left in the cool basement, to which they were transferred immediately after spraying, and in which they were left for four days after treatment.

The later transference to a constant temperature and humidity chamber was made on the assumption that the high humidity would assist the larvae to form cocoons since it would be nearer the conditions found in the soil. It was found, however, by the inspection on 8th July, 1944, that everything in the dishes except the cocoons was covered with mould and that considerable natural mortality had occurred. It was decided, therefore, to make an assessment of toxicity based on the inspections carried out between the 16th and 19th June, that is between four and seven days after treatment, at which time there was very little natural mortality.

It will thus be understood that the insects were not kept under optimum conditions after treatment and that the figures do not represent absolute toxicity for these conditions. However, it is hoped that they do give some idea of the relative toxicity of the different poisons, and of the concentrations necessary.

TABLE XIV.

Toxicities as contact poisons of Nicotine, DDT, Rotenone and the Pyrethrins to the penultimate stage larvae of *Pteronus ribesii*.

Concentration %	*Mortality*	*Percentage kill corrected for controls*
DDT w/v.		
0·2	27/30	90
0·1	23/30	76
0·05	22/30	73
0·025	20/30	66
0·0125	11/28	38
0·0062	3/28	8

$x = \log. (10^3 \times \text{conc.})$

Equation to the probit line adjusted for parallelism

$Y = 0{\cdot}93 + 1{\cdot}69\, x.$

TABLE XIV—*continued.*

Concentration %	*Mortality*	*Percentage kill corrected for controls*
Nicotine v/v.		
0·5	24/29	82
0·25	8/30	25
0·125	4/25	14
0·0625	7/29	22
0·0312	4/28	12

x = log. (10^3 x conc.)
Equation to the probit line adjusted for parallelism
$Y = -0\cdot82 + 1\cdot69\ x.$

Concentration %	*Mortality*	*Percentage kill corrected for controls*
Pyrethrins I and II w/v.*		
0·058	28/29	97
0·029	28/29	97
0·0145	27/29	93
0·0072	28/30	93
0·0036	28/30	93
Rotenone w/v.		
0·01	29/30	97
0·005	30/30	100
0·0025	27/30	90
0·0012	22/30	73
0·0006	10/30	31

x = log. (10^3 x conc.)
Equation to the probit line adjusted for parallelism
$Y = 3\cdot65 + 1\cdot69\ x.$

Unsprayed control	0/48
Carbitol control	2/31
Acetone control	1/28

The average of all three controls was used in calculating the corrected % kills.

* Pyrethrins made up from same stock and the proportions of the pyrethrins and the methods of estimation the same as in the experiment on *Pieris brassicae.*

Details of Experiment.
Date of spraying:—12/6/44.
Three replicas each of approximately 10 insects at each concentration except for the control where five replicas of ten were used.
Spraying pressure:—25·6 cm. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature:—73°F. Initial relative humidity:—66%.
End:— temperature:—72°F. End relative humidity:—66%.

Weights of Deposit.
Initial:—10% acetone medium = 7·3 mg./sq.cm. End:—7·2 and 7·3 mg./sq. cm.
End:—carbitol medium = 9·0 and 8·7 mg./sq.cm.
Temperature of storage basement immediately after spraying:—61°F.
Relative humidity of storage basement immediately after spraying:—62%.

Results.—A statistical analysis of the data by the Finney modification of the Bliss probit technique was made for DDT, nicotine and rotenone and lines were fitted. They were not found to depart significantly from parallelism and parallel lines were therefore fitted. All the concentrations tested with the pyrethrins gave a high kill, and the data were not susceptible to statistical treatment.

Table XIV gives the mortality figures for all poisons tested, together with the equations to the lines for DDT, nicotine and rotenone when these have been constrained to parallelism. Fig. 5 shows them graphically. A comparison of the relative potency for the three poisons is given in Table XV based on the L.D. 50.

Discussion of Results.—Judging from the results it seems that rotenone is much the most toxic contact poison to this species of the three compounds listed in Table XV and the data indicate that the pyrethrins may have similar toxicity. DDT, therefore, is less toxic than rotenone and almost certainly less toxic than the pyrethrins. Nicotine shows the least toxicity.

The dissimilarity in the medium employed with DDT from that used with the other poisons may alter the ratios of toxicity but the differences shown are large and it seems unlikely that the order would have to be altered if all the compounds had been tested in carbitol medium. The percentages for nicotine (95-96 per cent.) are given on a v/v basis, the others being w/v, but so large are the differences in potency that corrections for these have no significant effect.

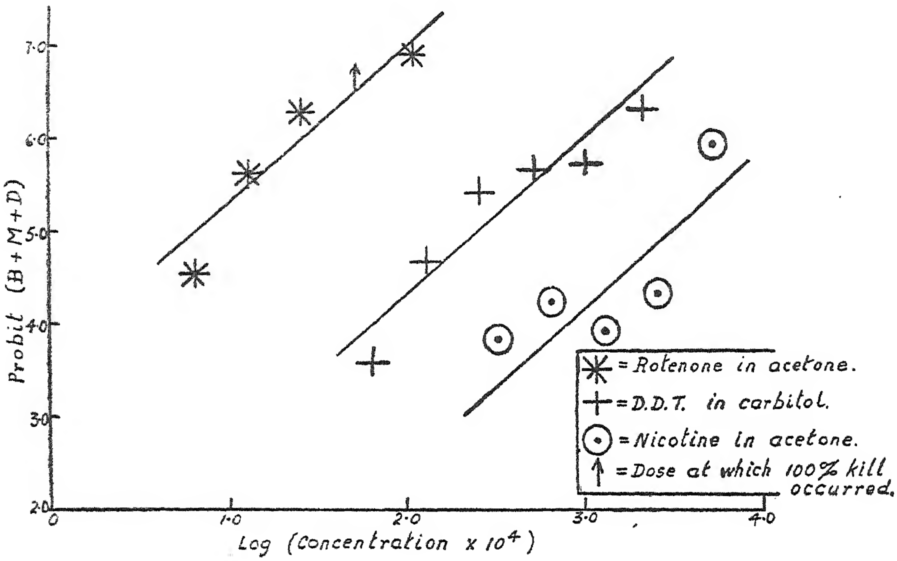

FIG. 5.—*Pteronus ribesii* (Gooseberry sawfly).

TABLE XV.

The relative potencies as contact poisons of DDT, Nicotine, Rotenone and the Pyrethrins to the penultimate stage larvae of *Pteronus ribesii*.

Insecticide and Medium	(m) 50	S.E.±	Antilog. m50/10⁴ = L.D.50	Relative potency
Nicotine in 10% acetone medium...	3·4558	0·073	0·286	1·0
DDT in carbitol medium	2·4136	0·066	0·026	11·0
Rotenone in 10% acetone medium	0·8030	0·087	0·0006	449·5

Pyrethrins in 10% acetone medium gave from 93–97% kill for concentrations ranging from 0·0036 to 0·058% w/v total pyrethrins.

Experiments on the Toxicity of DDT, Nicotine, Rotenone and the Pyrethrins to the Larvae of *Phymatocera aterrima*, Klug.

Some work on this insect has been done while studying the effect of various insecticides on the larvae of *Phymatocera aterrima* in 1941, 42 and 43. No detailed account of this earlier work is given here, since DDT was not included among the chemicals tested, except in one experiment in 1943 when the conditions were not strictly comparable. Some of these early data are, however, mentioned where it is thought they would add to the significance of the results obtained in 1944.

One outstanding defect in the earlier work was that the conditions provided after treatment did not allow the larvae to pupate and they consequently died. This rendered the assessment of results difficult, since it was not always possible

to determine whether the insects died as a result of the application of poison or because of the onset of pupation. The significance of the results themselves is also suspect since the conditions of after treatment were obviously unfavourable to the insects.

During these earlier experiments the insects were sprayed in a petri dish containing a circle of tricoline and kept in this manner, for the most part in a cool basement during the period of inspection. In the 1944 experiment the larvae after spraying in dishes containing a circle of tricoline and standing overnight in a cool basement were kept in water-saturated peat, as detailed under procedure, until death or pupation occurred. Under these conditions the insects were able to pupate satisfactorily and it is thought that the data, thus obtained, in these experiments represent the effect of the poisons under reasonably favourable conditions.

Two experiments were made and the following are the details and statement of results.

Experiment 1.

Insects.—The larvae were collected from Solomon's seal the night before the date of spraying and also on the morning of spraying, the former were kept on food in an outdoor insectary. The insects ranged in size from $\frac{2}{3}$ to $\frac{3}{4}$ grown; very few were fully grown.

Media.—DDT, 0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent v/v acetone. Nicotine, 0·1 per cent. w/v sulphonated lorol, 10 per cent. acetone v/v.

Procedure.—The larvae were put in 2 in. × 1 in. glass tubes on the morning and afternoon of spraying, 10 larvae per tube. They were treated by transferring into a 9 cm. petri dish containing a circle of tricoline covering the bottom and spraying them in the dish. The dishes were then covered with muslin, no food being added. When all had been treated they were transferred to a cool storage basement and kept there during the period that the insects were under observation. On the morning after treatment the insects and tricoline circles were removed from each dish which was three-quarter filled with powdered peat saturated with water by prolonged soaking, the insects and tricoline circles were then replaced and food added. Fresh food was added as required during the period of inspection.

Inspection and Method of Assessment of Results.—Five detailed inspections of the treated larvae were made on the third, fifth, eighth, twelfth and thirty-fourth day after treatment. All the larvae had pupated before the last inspection. The mortality figures were determined by deducting the number of pupae found in the final inspection from the original number of insects in the dish and calculating the percentages.

Experiment 2.

Insects.—The larvae for this experiment were derived from three sources. Some were collected and bred on a cut Solomon's seal in an outdoor insectary, others were collected the day before spraying from Solomon's seal in a garden and we are indebted to Mr. R. B. Benson, of the British Museum of Natural History, for the larvae that we used in the test on pyrethrins.

Nearly all the larvae were in the penultimate or last stage instar.

Media.—DDT in 0·1 per cent. w/v sulphonated lorol T.A., 1·5 per cent. v/v carbitol, 0·5 per cent. v/v acetone. Nicotine, Rotenone, Pyrethrins:—0·1 per cent. w/v sulphonated lorol, 10 per cent. v/v acetone.

Procedure.—This was the same as in Experiment 1.

Inspection and Method of Assessment of Results.—These insects were near to pupation when treated and only two detailed inspections were made, on the 4-5th and 14th day after treatment. Pupation was not quite complete at the last

inspection. The mortality figures were determined by adding for each dish the total number of dead to the affected insects in the last inspection and recording this as a fraction of the total number of insects in the dish.

TABLE XVI.

Toxicities as contact poisons of DDT and Nicotine to the larvae of *Phymatocera aterrima*.

Concentration %	*Mortality*	*Percentage kill corrected for controls*
DDT in carbitol medium w/v.		
0·1	29/29	100
0·05	30/30	100
0·025	32/32	100
0·0125	30/30	100
0·0062	20/30	65
Nicotine in 0·1% *sulphonated lorol and* 10% *v/v acetone.*		
0·5	28/32	87
0·25	17/31	53
0·20	13/29	42
0·15	10/31	29
0·125	8/30	23
0·10	8/34	20
Carbitol control	0/29	x = log. (10^2 x conc.)
10% acetone control	4/31	Equation to the probit line
Unsprayed control	0/31	$Y = -1{\cdot}72 + 2{\cdot}86\,x$.

* The average of all three controls was used in calculating the corrected % kills.

Details of treatment.
Date of spraying:—30/6/44.
Three replicas each of 10 insects.
Spraying pressure:—21·75 cms. Hg. Gap 1 $\frac{7}{10}$".
Initial temperature:—79°F. Initial relative humidity:—66%.
End temperature:—not recorded. End relative humidity:—not recorded.
Temperature of storage basement immediately after spraying = 64°F.
Relative humidity of storage basement immediately after spraying = 68%.

Storage of larvae after treatment.
Temperature:—62–66°F. Relative humidity:—58–79%.

TABLE XVII.

Toxicities as contact poisons of DDT, Nicotine, Rotenone and the Pyrethrins to the larvae (penultimate and final instar) of *Phymatocera aterrima*.

Concentration %	*Mortality*	*Percentage kill corrected for controls*
Nicotine in 10% *acetone.*		
0·5 v/v	14/30	44
0·375 v/v	11/30	34
0·25 v/v	9/30	27
0·20 v/v	7/30	20
0·15 v/v	4/29	10
	x = log. (10^3 x conc.) Equation to the probit line $Y = -0{\cdot}29 + 1{\cdot}91\,x$.	
Rotenone in 10% *acetone.*		
0·0125 w/v	29/30	97
0·0062 w/v	30/30	100
0·0031 w/v	29/30	97
0·0025 w/v	21/30	69
0·0016 w/v	21/30	69

TABLE XVII—*continued.*

Concentration %	Mortality	Percentage kill corrected for controls
DDT in carbitol medium.		
0·025 w/v	12/30	37
0·0125 w/v	16/29	53
0·0062 w/v	0/30	0
0·0031 w/v	1/28	0
0·0016 w/v	6/30	16
Pyrethrin I and II† in 10% acetone medium.		
0·007 w/v	28/30	93
0·0052 w/v	27/30	90
0·0035 w/v	27/30	90
10% acetone control	0/31	
Carbitol control	4/30	
Unsprayed control	0/30	

The average of all controls was used in calculating the corrected % kills.

† Pyrethrins made up from same stock; the proportions of pyrethrins and methods of estimation the same as in experiments on *Pieris brassicae* and *Pteronus ribesii.*

Details of Treatment.

Date of spraying:—10/7/44.
Three replicas each of 10 insects.
Spraying pressure:—23·7 cm. Hg. Gap 1 $\frac{7}{10}$″.
Initial temperature:—71°F. Initial relative humidity:—73%.
End temperature:—73°F. End relative humidity:—74%.

Weights of Deposits.

Acetone medium. Initial:—7·1 mg./sq.cm. End:—7·2 and 7·1 mg./sq. cm.
Temperature of storage basement immediately after spraying:—64°F.
Relative humidity of storage basement immediately after spraying:—73%.

Storage of insects after treatment.

Temperature 63–65°F. Relative humidity 62–78%. Registered on a recording thermograph and a recording hair hygrograph.

Results.—The data for both experiments are set out in Tables XVI and XVII. Unfortunately very little of the data was suitable for statistical analysis since the concentrations chosen only gave a suitable range of kill with nicotine and with this insecticide the equations to both lines are given.

Discussion of Results.—In the first experiment it appears that DDT is much more toxic to Solomon's seal sawfly larvae than nicotine and this is confirmed by the results of the second experiment; it seems likely that the toxicity of DDT is of the order of 20 to 40 times that of nicotine. Judging from the results of the second experiment it appears that both rotenone and the pyrethrins are considerably more toxic to the fully grown larvae than DDT, a rough estimate would be that both are more than 25 times as potent as DDT weight for weight.

It is interesting to note the increase in resistance of the fully grown larvae used in the second experiment over the $\frac{2}{3}$-$\frac{3}{4}$ grown insects used in the first. Statistical analysis of the data on the toxicity of nicotine for both experiments showed them not to be heterogeneous and two lines were plotted, these are shown in fig. 6. These lines do not appear to depart significantly from parallelism and a comparison of the L.D. 50s shows that the fully grown larvae are a little over twice as resistant as the $\frac{1}{3}$-$\frac{3}{4}$ grown larvae. Judging from the data an increase of resistance of the same order also appears to occur with DDT.

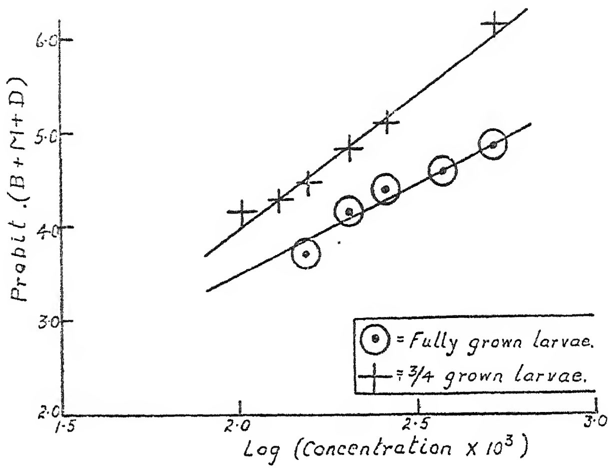

FIG. 6.—*Phymatocera aterrima* (Solomon's Seal Sawfly). Difference in resistance to nicotine of threequarters grown larvae and fully grown larvae.

Summary and Conclusions.

The toxicity of DDT as a contact spray under laboratory conditions has been tested on a number of insect species. The particulars of the species used are set out below.

Order	Species	English name	Stage
Hemiptera ...	*Aphis fabae*, Scop. ...	Black bean aphis ...	Apterous viviparous parthenogenetic females.
,, ...	*Myzus cerasi*, F.	Cherry black fly ...	Apterous viviparous parthenogenetic females.
Coleoptera ...	*Phaedon cochleariae*, F. ...	Mustard beetle... ...	Adults.
Lepidoptera ...	*Cheimatobia brumata*, L....	Winter moth	Larvae.
,, ...	*Hyponomeuta cognatella*, Hb.	Small ermine moth ...	,,
,, ...	*Pieris brassicae*, L. ...	Cabbage white butterfly	,,
Hymenoptera	*Pteronus ribesii*, Curtis ...	Gooseberry sawfly ...	,,
,, ...	*Phymatocera aterrima*, Klug	Solomon's seal sawfly...	,,

The toxicity of the DDT spray was compared in every instance with nicotine. A rotenone or derris suspension was included in the tests on *Myzus cerasi, Phaedon cochleariae, Pieris brassicae, Pteronus ribesii* and *Phymatocera aterrima*, and a pyrethrin spray in the tests on *Pieris brassicae, Pteronus ribesii* and *Phymatocera aterrima*.

The results of these tests are summarised in Table XVIII.

TABLE XVIII.

Summary of the data on the various poisons tested.

Species	Stage	Mortality level†	Relative toxicity
Aphis fabae	Apterous viviparous parthenogenetic females	—	DDT (M3*) similar to nicotine (M1*).
Myzus cerasi	Apterous viviparous parthenogenetic females	L.D.50 (lines parallel)	Rotenone (M1) 91·3, DDT (M2*) 1·7, Nicotine (M1) 1·0.
Phaedon cochleariae ...	Adults	L.D.75	Rotenone (M1) 72·4, Rotenone (M2) 49·1, DDT (M2) 14·5, Nicotine (M1) 1.
	,, ...	L.D.50	Rotenone (M1) 109·7, Rotenone (M2) 47·0, DDT (M2) 16·4, Nicotine (M1) 1.
	,, ...	L.D.25	Rotenone (M1) 124·7, Rotenone (M2) 41·6, DDT (M2) 18·7, Nicotine (M1) 1.
Cheimatobia brumata	⅓ to fully grown larvae	L.D.50 (lines parallel	DDT (N2) 80·6, Nicotine (M2) 1.
Hyponomeuta cognatella	Fully grown larvae	—	DDT much more toxic than Nicotine (M2).
Pieris brassicae ...	,, ,, ,,	L.D.75	Pyrethrin (M1) 36·4, Pyrethrin (M2) 28·5, DDT (M2) 10·5, Derris elliptica (M2) 6·4, Nicotine (M1) 1.
	,, ,, ,,	L.D.50	Pyrethrin (M1) 25·9, Pyrethrin (M2) 20·3, DDT (M2) 6·2, Derris elliptica (M2) 5·3, Nicotine (M1) 1.
	,, ,, ,,	L.D.25	Pyrethrin (M1) 21·2, Pyrethrin (M2) 16·2, DDT (M2) 3·6, Derris elliptica (M2) 4·3, Nicotine (M1) 1.
Pteronus ribesii ...	Penultimate stage larvae	L.D.50 (lines parallel)	Rotenone (M1) 449·5, DDT (M2) 11, Nicotine (M1) 1, Pyrethrins (M1) probably similar to rotenone.
Phymatocera aterrima	⅓ to fully grown larvae	—	Pyrethrins (M1) and Rotenone (M1) similar, both more toxic than DDT (M2); DDT (M2) more toxic than Nicotine (M1).

† Mortality level at which the numerical comparison was made.
* M1. = Medium 0·1% w/v sulphonated lorol, 10% v/v acetone.
M2. = ,, 0·1% w/v ,, ,, T.A., 1·5% v/v carbitol, 0·5% v/v acetone.
M3. = ,, 0·1% w/v ,, ,, 4% w/v Belloid T.D., 10% v/v acetone.

Estimating on a basis of equal content of toxic ingredient, DDT appeared to be more toxic than nicotine to all the species studied except the aphids. The toxicity of these two poisons to *Aphis fabae* appeared to be similar, and to *Myzus cerasi* DDT appeared to be twice as toxic as nicotine but owing to the length of time DDT took to kill and the amount of reproduction occurring, it did not appear that it would be as effective in practice as nicotine.

DDT was much less toxic than rotenone to the sawfly, and to the beetle and aphid species on which it was tested, but was more effective against the lepidopterous species, where it was found necessary to substitute a derris resin for pure rotenone in order to get a range of kills.

The pyrethrins were only included in the tests with *Pieris brassicae* and the two species of sawfly, and in every instance proved more toxic, weight for weight, than DDT.

It appears that rotenone was more toxic in acetone medium than in carbitol medium to adult *Phaedon cochleariae* but the pyrethrins did not show a significant difference in these two media when tested on the larvae of *Pieris brassicae*.

It must be emphasised that these results are only intended as a measure of the contact effect under laboratory conditions and do not take into account any stomach poison effect or difference in stability and retention under outdoor conditions.

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THE EFFECT OF MEDIUM ON THE TOXICITY OF DDT TO APHIDS.

By F. Tattersfield, C. Potter & Mrs. E. M. Gillham.

In 1943 it was found that DDT was relatively ineffective as an insecticide to certain species of aphids. It was suggested that the medium in which it was incorporated might play an important part in the effect, particularly since it appeared that aggregation of crystals might be a limiting factor in the toxicity of suspensoids of this compound. It was, therefore, decided to test out DDT in various media.

Unfortunately 1944 proved a difficult year for rearing aphids free from parasitism and disease, and less was accomplished than had been hoped for, but certain indications were obtained that the nature of the medium had an effect upon the toxicity of DDT. Dr. H. Martin kindly suggested and provided us with several samples of concentrates, two of which were tried out fairly thoroughly and since they afford an example of two contrasted types of media likely to be met with in practice, they are given here.

(*a*) 5 gm. DDT dissolved in 75 gm. carbitol, 5 gm. sulphonated lorol T.A. and 20 gm. acetone, this gives a concentrate of 5 per cent. w/v of DDT.

On diluting to 0·1 per cent. w/v DDT this gave a solution in water of 1·5 per cent. w/v carbitol, 0·1 per cent. w/v sulphonated lorol T.A. and 0·4 per cent. w/v acetone, the DDT being present in finely dispersed *solid* state.

(*b*) 5 gm. DDT, 15 gm. benzene, 1 gm. anhydrous cyclohexylamine dodecyl sulphate which on dilution with water gave a relatively stable emulsion, the DDT being in solution in the dispersed benzene phase.

Tests were carried out with the basal medium (*a*) on three species of aphids, with the object of choosing as test-subjects those species which were least affected by this medium alone. The aphid species treated were *Macrosiphoniella sanborni,* Gill., *Macrosiphum solanifolii,* Ashm., and *Myzus circumflexus,* Buckt. On one occasion the stored products pest, *Oryzaephilus surinamensis,* L., was used and in addition a few tests were made upon *M. sanborni* with a few alternative media (listed in Table I).

Procedure.—The aphids were allowed to migrate from the plant, counted off into tubes and sprayed in 9 cm. petri dishes containing a circle of tricoline. The dishes were afterwards covered with muslin and kept in a basement cellar at 18-20° C. until examined. The examination carried out after one and after two days was conducted on a warm plate kept at a temperature of 37-40° C., the insects being separated into categories of the unaffected, the slightly affected (able to walk), badly affected (showing marked paralysis), the moribund and those apparently dead. The results are given in Table I.

It is clear that only *Macrosiphum solanifolii* is resistant enough to medium (*a*) to be of use as a test subject. Data given under date 11/4/44 in Table I show that the sodium salt of sulphonated lorol was even more toxic to *Macrosiphoniella sanborni* than sulphonated lorol T.A. and that carbitol was clearly a toxic ingredient in the basal medium to the more susceptible aphids. *Macrosiphum solanifolii* was chosen, therefore, as the test subject. It was found later that medium (*b*) diluted with water to correspond with a concentration of 0·1 per cent. DDT was not materially toxic to this aphid.

TABLE I.

Control tests with a basal medium upon three species of aphids.
Basal medium: Carbitol 1·5% w/v, acetone 0·4% w/v, Sulphonated lorol 0·1% w/v in water.

Insect used	Results after 1 day		Results after 2 days	
	% affected	% badly affected	% affected	% badly affected
Date: 30/3/44. Deposit: 6·3–7·2 mg./sq. cm. 5-fold replication, 10 insects a time.				
Macrosiphoniella sanborni	18	18	22	22
Macrosiphum solanifolii	—	—	5·1	1·7
Myzus circumflexus	—	—	20	14
Date: 4/4/44. Deposit: 7·4–7·6 mg./sq. cm. 5-fold replication, 10 insects at a time.				
Macrosiphoniella sanborni ... ... (sprayed)	26	26	46·8	44·7
,, ,, (not sprayed)	2	—	14	6
Myzus circumflexus (sprayed) ...	—	6	22·9	22·9
,, ,, (not sprayed)	6·2	4·1	27·3	25
Oryzaephilus surinamensis ... ... (sprayed)	—	—	—	7·9
,, ,, (unsprayed)	—	—	0	0
Date: 11/4/44. Tests with constituents of certain basal media on *Macrosiphoniella sanborni*				
Unsprayed		2·1		
0·1% Sulphonated lorol (Na salt) + 0·4% w/v acetone		18·4		
0·1% Sulphonated lorol T.A. + 0·4% w/v acetone		4		
1·5% w/v carbitol 0·1% w/v Sulphonated lorol (Na salt) + 0·4% w/v acetone		20·4		
1·5% w/v carbitol, 0·1% w/v Sulphonated lorol T.A. + 0·4% w/v acetone		16		

Since DDT is slow in its toxic action it was decided to carry out tests to ascertain how many days after spraying this insect could be safely left before a final examination. The results of two separate sprayings are given in Table II.

Obviously the slow-acting effect of DDT presents difficulties in assessing its toxic action. Even if all the affected insects, *i.e.*, showing paralysis from slight to deep, were taken into account on the second day after spraying, it would probably give an under-estimate of the toxicity, while taking them on the third day, unless controls were better than in the above series of tests, might probably give an over-estimate.

TABLE II.

Tests to ascertain the effect on *Macrosiphum solanifolii* of the time elapsing between spraying and examination.

Sprayed 18/4/44	%	Examination on 20/4/44		21/4/44	
		% affected	% badly affected	% affected	% badly affected
Basal medium (carbitol-acetone - sulphonated lorol T.A.)	—	4·2	4·2	19·1	19·1
DDT in basal medium ...	0·075	89·8 (89·3)	53·1 (51·0)	100 (100)	93·9 (92·5)
,, ,, ,, ,, ...	0·05	34·8 (31·9)	17·4 (13·8)	93·6 (92·1)	63·8 (55·2)
,, ,, ,, ,, ...	0·025	29·8 (26·7)	25·5 (22·2)	70·8 (63·9)	62·5 (53·6)
,, ,, ,, ,, ...	0·0125	23·9 (19·5)	17·4 (13·8)	46·5 (33·9)	41·9 (28·2)

Figures in brackets are corrected for controls. Deposit 6·9–7·5 mg./sq. cm.

Sprayed 2/5/44		Examination 4/5/44		5/5/44	
Basal medium (as above)	—	5·12	5·12	23·7	23·7
DDT in above medium ...	0·1	90·0 (89·4)	80·0 (78·9)	95·5 (94·6)	91·8 (89·2)
,, ,, ,, ,, ...	0·075	89·8 (89·3)	55·1 (52·7)	100 (100)	91·5 (88·85)
,, ,, ,, ,, ...	0·05	72·5 (71·0)	47·1 (44·3)	92·2 (89·8)	88·2 (84·5)
,, ,, ,, ,, ...	0·025	46·0 (43·1)	44·0 (41·0)	72·3 (63·7)	70·2 (60·9)
,, ,, ,, ,, ...	0·0125	31·4 (27·7)	27·4 (23·5)	59·2 (46·5)	57·1 (43·8)

Deposit: 6·44–6·9 mg./sq. cm.

Comparing the two sections of Table II, it will be seen that despite high values in the controls, the third day's results are in closer agreement with each other than the second day's in the two series of tests.

Reproduction took place at all concentrations. There is a tendency towards fungal disease with these aphids which probably affects their susceptibility, but as it was the most highly resistant species available, it appeared advisable to try and rear a stock as free from this defect as possible and to make use of it for critical evaluations.

A feature of many of the tests was the frequency with which a smaller toxic value was obtained at 0·1 per cent. DDT than at 0·075 per cent. or even at 0·05 per cent. This was almost certainly due to aggregation or increase in particle size after diluting the concentrate. In more extreme cases this resulted in the partial silting up of the very fine nozzle used in the spraying. In further tests, therefore, dilutions of the concentrates were made immediately before spraying, which was carried out at the highest possible speed.

Two series of tests were carried out, using *Macrosiphum solanifolii* as test subjects, in which the toxicity of DDT as a suspensoid was contrasted with its toxicity when used as an emulsion in benzene. The details of the media and the

results are given in Tables III and IV. One important difference in treatment between the two series was that, in the first, the insects were examined both two days and three days after treatments, whereas in the second series examination was confined to the third day, since it was considered that the mere process of examination might have a deleterious effect on the insects. The data were examined statistically by the method of probits, and it was found that those obtained with the acetone-carbitol medium (suspensoid) showed some tendency towards heterogeneity, x^2 having a not-quite-significant value on the first occasion (Table III) and being just significant on the second (Table IV). This may well be due to the tendency to aggregation in particle size in these cases; the emulsions showed no such tendency. The third day's results are plotted in fig. 1.

An examination of the Tables III and IV and fig. 1 indicate that the insecticides were on the whole less effective on the later date (Table IV) and this may well have been due to the two examinations to which the insects were subjected on the first occasion.

TABLE III.

Comparison of toxicity of DDT in two media.

	% DDT	% affected 4/5/44	% badly affected 4/5/44	% affected 5/5/44	% badly affected 5/5/44
Basal medium (a) (Control) 1 2	0·0	2·04, 2·17 } 2·1	2·04, 2·17 } 2·1	9·09, 11·36 } 10·22	6·82, 11·36 } 9·09
DDT in (a)	0·1	62·3 (61·5)	33·3 (31·9)	89·0 (87·7)	88·3 (87·1)
,, ,, ,, ...	0·075	60·8 (60·0)	23·5 (21·9)	90·2 (89·1)	80·4 (78·4)
,, ,, ,, ...	0·05	46·9 (45·8)	18·4 (16·7)	83·3 (81·4)	64·6 (61·1)
,, ,, ,, ...	0·025	32·6 (31·15)	5·7 (3·7)	57·45 (52·6)	42·6 (36·9)
,, ,, ,, ...	0·0125	10·4 (8·5)	8·3 (6·3)	48·9 (43·1)	46·8 (41·5)
Basal medium (b) ... (Control)	—	1·96, 0·00 } 0·98	1·96, 0·00 } 0·98	2·08, 10·87 } 6·47	2·08, 8·70 } 5·39
DDT in (b)	0·1	78·0 (77·8)	38·0 (37·4)	98·0 (97·8)	94·0 (93·7)
,, ,, ,, ...	0·075	66·0 (65·7)	37·7 (37·1)	100 (100)	98·0 (97·9)
,, ,, ,, ...	0·05	54·0 (53·6)	26·0 (25·3)	98·0 (97·8)	86·3 (85·5)
,, ,, ,, ...	0·025	39·0 (38·4)	29·3 (28·6)	90·4 (89·7)	88·5 (87·8)
,, ,, ,, ...	0·0125	15·2 (14·4)	2·2 (1·2)	80·4 (79·0)	71·7 (70·1)

Sprayed 9/5/44.

Basal media: (a) Carbitol 1·5% v/v, acetone 0·5% v/v, sulphonated lorol T.A. 0·1% w/v in water.

(b) Benzene solution containing 6·25% w/w cyclohexylamine sulphonated lorol 4·3 ml. is diluted to 100 ml. with water.

Spray deposits mg./sq. cm. = 6·9, 7·2 Test subject: *Macrosiphum solanifolii.*

Tests carried out in fivefold replication, 10 insects at a time.
There was reproduction throughout the tests.
Figures corrected for controls are in brackets.

TABLE IV.

Comparison of toxicity of DDT in two media.

	% DDT	% affected	% affected corrected for control	% badly affected	% badly affected corrected for control
Basal medium (a) (control) ...	—	14·29	—	14·3	—
DDT in (a)	0·1	88·0	86·0	63·0	55·7
,, ,, ,, ...	0·05	81·8	78·8	72·7	68·2
,, ,, ,, ...	0·025	56·5	49·3	34·8	23·9
,, ,, ,, ...	0·0125	54·2	46·5	39·6	29·5
,, ,, ,, ...	0·0062	16·0	2·0	16·0	2·0
Basal medium (b) (control) ...	—	15·9	—	13·6	—
DDT in (b)	0·1	98·1	97·7	76·9	73·3
,, ,, ,, ...	0·05	95·4	94·6	77·3	73·7
,, ,, ,, ...	0·025	95·6	94·8	69·6	64·7
,, ,, ,, ...	0·0125	77·5	73·3	59·2	52·7
,, ,, ,, ...	0·0062	48·9	39·3	46·8	38·4

Media :—(a) Carbitol, acetone, sulphonated lorol T.A. in water as before.
(b) Benzene-cyclohexylamine sulphonated lorol in water as before.

Deposit: (a) 7·4–7·5 mg./sq. cm. (b) 7·6 mg./sq. cm.

Test subject: *Macrosiphum solanifolii.*

Date of spraying: 2/6/44.

One examination only after three days.

Tests carried out in fivefold replication, 10 insects at a time.

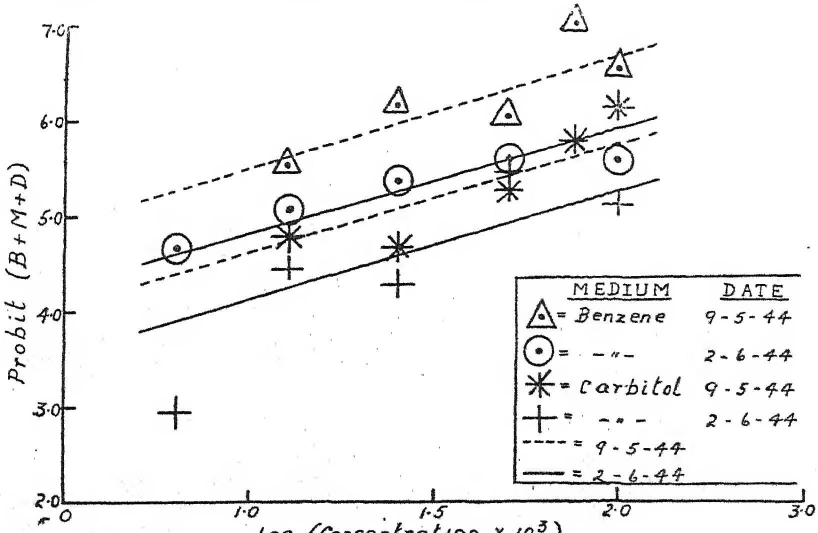

FIG. 1.—*Macrosiphum solanifolii.* Comparison of the insecticidal values of DDT in two media.

The results obtained for the relative potency of DDT in the two media are given in Table V. The data show that DDT is 4-6 times as toxic to *Macrosiphum solanifolii* when applied in the emulsified form in medium (*b*) as in the suspensoid form in medium (*a*).

TABLE V.

Comparison of the insecticidal values of DDT in two media.

(Summary)

Macrosiphum solanifolii

Date	Medium	Log median lethal concn. (pts/100,000) m 50	SE ±	Antilog m50/10³ = LD 50	Relative potency
9/5/44	(a) Carbitol-acetone sulphonated lorol T.A.	1·3243	0·13	0·0211	1·0
	(b) Benzene cyclohexylamine sulphonated lorol	0·5225	0·32	0·0033	6·3
2/6/44	(a)	1·7297	0·21	0·0537	1·0
	(b)	1·1441	0·1	0·0139	3·9

The difference from parallelism was not significant.
Equations of lines constrained to parallelism are:—
Medium (a) 9/5/44 $Y = 3{\cdot}53 + 1{\cdot}11x$
,, (b) ,, $Y = 4{\cdot}42 + 1{\cdot}11x$
,, (a) 2/6/44 $Y = 3{\cdot}08 + 1{\cdot}11x$
,, (b) ,, $Y = 3{\cdot}73 + 1{\cdot}11x$

Summary.

It is shown that the insecticidal value to *Macrosiphum solanifolii* of DDT depends upon the medium in which it is incorporated. It is more toxic (4-6 times) when dispersed as an emulsion dissolved in a water-insoluble solvent (benzene) than when dissolved in a water-soluble solvent (acetone-carbitol) and dispersed as a suspensoid.

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ON THE IDENTITY OF THE COTTON CAPSID OF UGANDA.

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For some years prior to 1935, the cotton Capsid of Uganda, which is now known to occur in several other parts of Africa also, was called *Lygus vosseleri*, Popp. In 1935, Mr. W. E. China of the British Museum (Natural History), after examining type material, published a note synonymising *vosseleri* of Poppius with *simonyi* of Reuter and concluded that the cotton Capsid previously identified by him as *L. vosseleri*, Popp., must therefore be called *L. simonyi*, Reut. This latter name has been in general use for the cotton Capsid since 1935 and is very widely known because of the great importance of the insect as a pest of cotton.

In connection with field work on this insect in Africa (Taylor, 1945), it was necessary to study a very large number of specimens of this and other African species of *Lygus*. The species were separated primarily on the basis of certain structures of the male genitalia, which proved to be absolutely diagnostic unlike almost all other characters in this difficult genus. On this basis the cotton Capsid proved to be very distinct from all other related species, some of which it closely resembles in all other respects. The differences in genitalia were subsequently correlated with the few other differences which exist, such as those in markings, colour and size. Reliable determination of females as well as males was thus made possible.

The species known in Uganda were then compared with type material kindly lent by the authorities of the Paris, Helsinki, Vienna and British Museums. It was found that the cotton Capsid is, after all, *vosseleri*, Popp., not *simonyi*, Reut., and that *simonyi*, Reut., 1903, and *schonlandi*, Dist., 1904, are identical.

The type and other reliably-named material on which these conclusions are based is as follows :—

L. schonlandi, Dist.

1♂ and 1♀ (type) from the grounds of the Albany Museum, Grahamstown, S. Africa, xi-01, bearing the initials M.D. and M.S.

1♀ from Durban, Natal (Marshall), determined by Distant, but without other data.

These three specimens are all in the British Museum.

L. simonyi, Reut.

1♂, Caffraria, determined by Reuter, but without other data : in the Helsinki Museum.

1♂, 1♀, Aden, xii.98, "leg. O. Simony," determined by Reuter : in the Vienna Museum. (These are to be regarded as cotypes, Aden being the type locality.)

L. vosseleri, Popp.

1♀, labelled "Madagaskar, Ambodimanga, Hammerstein S., 1906" and "*Lygus vosseleri* n. sp., B. Poppius det." : in the Helsinki Museum. (This is to be regarded as a cotype, as it undoubtedly belonged to the original series examined by Poppius, who did not fix his types.)

All these specimens were mentioned by Poppius (1912, 1914) and were presumably examined by him, though, as China has pointed out, the Aden specimens of *simonyi* are in the Vienna Museum, not the Paris Museum as Poppius stated.

The male genitalia show that Distant's *schonlandi* and Reuter's *simonyi*, though differing in colour and in distinctness of markings, are merely extreme forms of the same species, and that this species, which is common in Uganda on various plants other than cotton and is only a rare visitor on cotton, is quite distinct from the so-called cotton Capsid. Distant's material came from South Africa and the specimens are relatively dark and rather large, while Reuter's specimens came from Aden and are rather small and pale, as one would expect from the arid conditions prevailing there. All possible intermediate forms, as well as the two extremes, occur in Uganda. The same degree of variation occurs in the cotton Capsid and in several other species of the genus. In this connection it is interesting to note that Poppius himself was in some doubt as to the identity of Distant's *schonlandi*, as he remarked that it is very nearly related to *L. simonyi*, Reut., and is perhaps identical with it. It is now clear that his suspicion was justified and that the name of the species concerned is *simonyi*, Reut., while the name *schonlandi* of Distant becomes a synonym. Since genitalia were not examined by Reuter, Distant or Poppius and the material at their disposal was very scanty, it is not surprising that confusion arose.

Owing to difficulties arising from the war, it has been impossible to obtain for examination any of the specimens of *vosseleri* known to Poppius except the one mentioned above, which is a female. Others are in the Berlin and Genoa Museums, but it is not known whether they include a male, or even whether they still exist. China, in discussing *simonyi*, *vosseleri* and the cotton Capsid, remarks that "the genitalia were studied and found to correspond" and this implies that he received at least one male of *vosseleri* from the Helsinki Museum, whence the type material which he studied came. The material received from the Helsinki Museum in connection with the present investigation does not include a male, and subsequent enquiry has shown that there is no more material there. It seems likely, therefore, that a male has been lost. The important point is, however, that at the time when China made his examination, the material at his disposal was very scanty and the number of species known from Africa was very small, so that it was then impossible to assess accurately the full importance of the characters afforded by the genitalia. He was justified in stating that the genitalia of *simonyi* and the cotton Capsid (or *vosseleri*) "correspond," since they are of the same general form though differing markedly and constantly in certain details. It was not until many species related to the cotton Capsid were collected in large numbers that it became evident that the differences in details were specific differences and were not mere variations within one species. Despite the fact that no type male is available for comparison, there is no doubt that the species represented by the female specimen from Madagascar and determined by Poppius himself as *vosseleri* is quite distinct from *simonyi*, Reut., and is identical with the cotton Capsid of Uganda.

Poppius, in his list of localities for *vosseleri*, included Amani (Tanganyika) and remarked that the species is injurious to *Ricinus* there. The cotton Capsid, however, is rarely found on *Ricinus*, which is severely attacked by a closely related and very similar species. Poppius' description of *vosseleri*, while applying to the cotton Capsid, does not apply in all respects to the species which commonly attacks *Ricinus*, and it seems probable that the specimen from Amani was erroneously assumed to be identical with the other specimens mentioned by Poppius, which are probably all *vosseleri*, the cotton Capsid.

Redescriptions of *vosseleri*, Popp., and *simonyi*, Reut., will appear, with descriptions of several other species and notes on host plants, in a paper which will be published as soon as space is available and which, though completed a year ago, has not hitherto been published because of the necessity of establishing the identity of the cotton Capsid first. The material from the Helsinki and Vienna Museums has made this possible, and this preliminary note has been written to emphasize

that the name of the cotton Capsid is *vosseleri*, Popp., not *simonyi*, Reut. This change of name, or rather this reversion to the name first used for the cotton Capsid, is regrettable because the insect is very well known to all concerned with cotton-growing in Africa ; nevertheless, the correction is necessary in order to avoid further confusion.

I particularly wish to add that I have discussed this whole question fully and frequently with Mr. W. E. China, who read this note in manuscript at my request and whose advice and help I have much appreciated.

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THE INSECT PARASITES OF THE CARROT FLY, *PSILA ROSAE*, FAB.

By D. W. Wright, M.A., Q. A. Geering, B.A. & D. G. Ashby, M.A.
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Introduction.

During the course of a study of the biology of the carrot fly, *Psila rosae*, F., in East Anglia, observations were made on the parasitic insects attacking this pest. The principal insects concerned were two species of Hymenoptera, *Dacnusa gracilis*, Nees (Braconidae, Dacnusinae) and *Loxotropa tritoma*, Thoms. (Proctotrupoidea, Diapriidae). Both were widespread in East Anglia, with *D. gracilis* the more numerous. Two other parasites were also encountered, both in small numbers. These were *Aleochara sparsa*, Heer (Staphylinidae, Aleocharinae) which occurred in several localities and a Cynipoid of the genus *Kleidotoma* which was comparatively rare and obtained from only two places. The high parasitism occasionally achieved by *D. gracilis*, and to a lesser extent by *L. tritoma*, showed that these were potentially important agencies in restricting the increase of the carrot fly. This, together with the paucity of information available on all the parasites encountered, led to the collection of data on their biology and incidence during the years 1944 and 1945.

In the following paper an account is given of the life-history and development of *D. gracilis* and of *L. tritoma*. For *A. sparsa*, where less information was obtained, descriptions are given of only certain immature stages. References are given to descriptions of the adult stages of these parasites and hence are not included in this paper.

Dacnusa gracilis, Nees (1834).

D. postica, Haliday (1839).
D. egregia, Thomson (1895).

Distribution.

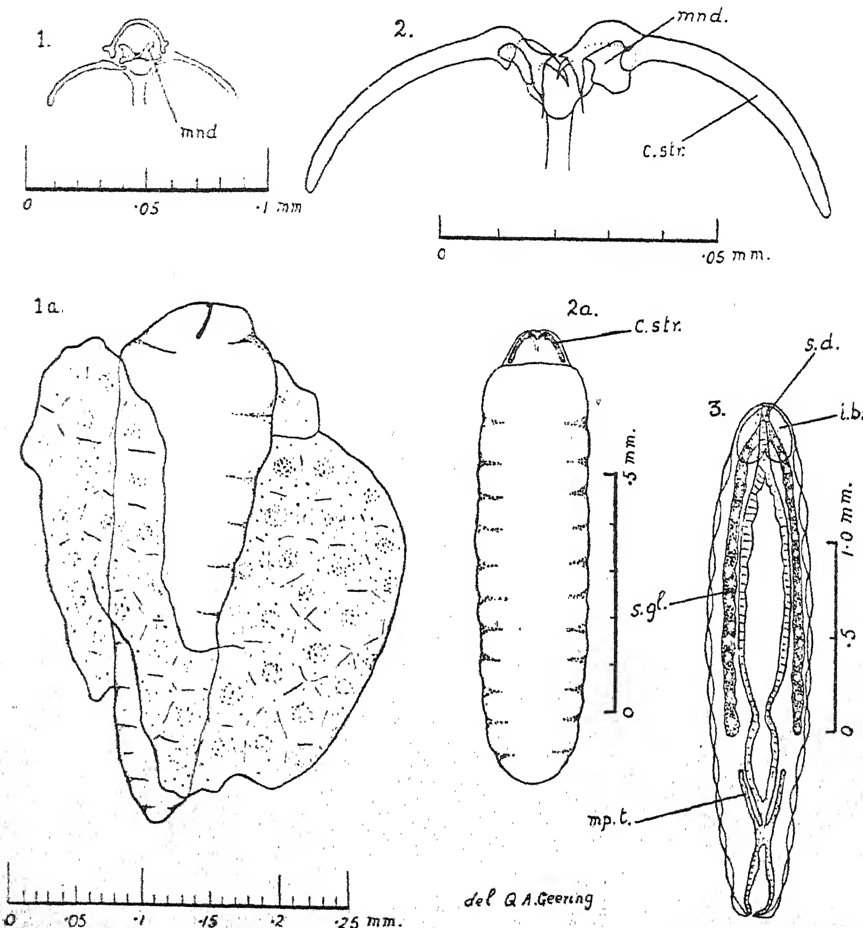
The writers have found *D. gracilis* parasitising the carrot fly, *P. rosae*, in the fen areas of Cambridgeshire, the Swaffham district of Norfolk, at Kirton in Lincolnshire, at St. Albans in Hertfordshire, and at Cambridge. In his paper on the British species of *Dacnusa*, Nixon (1937) uses the synonym *D. postica*, Hal., and records it as having been bred from *P. rosae* in the Manchester district (Smith & Gardner, 1922) and from Lausanne. Adults are also recorded from Huntingdonshire, Kent, Inverness-shire (Scotland) and Sligo (Ireland). From the Leningrad district of Russia, Savzdarg (1927) refers to a Braconid of the genus *Dacnusa* contributing to the annual fluctuations of the carrot fly population, saying, "It emerged in spring at the same time as *P. rosae*, viz. 24th May to 2nd July. In 1924 spring cocoons were 20 per cent. parasitised; in 1925 spring cocoons were 35 per cent. parasitised." The behaviour of this parasite in relation to its host would again suggest it to be *D. gracilis*.

The immature Stages.

The immature stages of *D. gracilis* are passed in the larvae and puparia of the carrot fly. Attempts to observe the parasite in the act of oviposition were not successful and the egg stage was not found; the stages of the host which are selected for parasitism cannot therefore be definitely stated. However, observation on host material collected in the field showed first-instar parasite larvae in both second- and third-instar carrot fly larvae. From puparia, the youngest parasite larva recorded was in the 2nd instar. This would indicate that the parasite only oviposits

in the larval stages of the host. Further evidence, suggesting that all the larval stages of the host may be attacked, was obtained from a study of the carrot fly larval populations during autumn and winter. In these, the level of parasitism by *D. gracilis* measured at the time of pupation of the host was very similar for larvae which had been at all stages of development in early autumn when the adult parasites were active.

In the life-cycle of *D. gracilis* there are four larval instars and a well-defined prepupal stage ; and in all instars the body is divided into a head and twelve trunk segments. In only two other species of *Dacnusa* has the larval development been investigated and in both of these only the first and last instars have been described. In the following account, the four larval instars of *D. gracilis* are described and illustrated, together with the prepupal and pupal stages.



Figs. 1–3.—*D. gracilis* larval instars. (1) 1st instar, mouth-parts and head structures ; (1a) 1st instar larva within trophamnion (broken) ; (2) 2nd instar, mouth-parts and head structures ; (2a) fully grown 2nd instar ; (3) anatomy of 3rd instar, diagrammatic. c. str. cephalic strut ; i.b. imaginal bud ; mnd. mandible ; mp.t. malpighian tubule ; s.d. salivary duct ; s.gl. salivary gland. (1–2 camera lucida.)

The first Instar.

This instar in appearance and habit is very similar to the first instar of *D. areolaris*, Nees, described by Haviland (1922). It develops within an enlarged trophamnion; one specimen was found to measure 0·37 mm. by 0·12 mm. The mouth-parts (fig. 1) consist of a pair of well-defined mandibles; these are short and subconical, with sharp apices, and in shape resemble those of the fourth instar. They measure 10μ in length. Associated chitinous bars are present, together with an arched dorsal rod over the mouth. Unlike the first instar of *D. navicularis* var. *cynaraphila*, Ric., described by Ricchello (1928), this instar of *D. gracilis* possesses no paired setate appendages on the trunk segments. At ecdysis the first larval skin is left within the trophamnion and the second instar emerges to live freely in the host's body fluid. Fig. 1a shows the first instar larva enclosed by the trophamnion—the latter having broken.

The second Instar.

When first formed the second-instar larva (fig. 2a) measures 0·46 mm. in length and grows to 1·2 mm. before moulting. The distinguishing features of this instar are again the mouth-parts and associated structures. The head region shows laterally two curved, heavily chitinised, strengthening bars and articulating with these are the sharp, curved, mandibles measuring 15μ in length (fig. 2). There are no indications of maxillae or other trophi. In the anal region are four minute setae and when this instar is fully grown a pair of prominent imaginal buds appear internally in the anterior region.

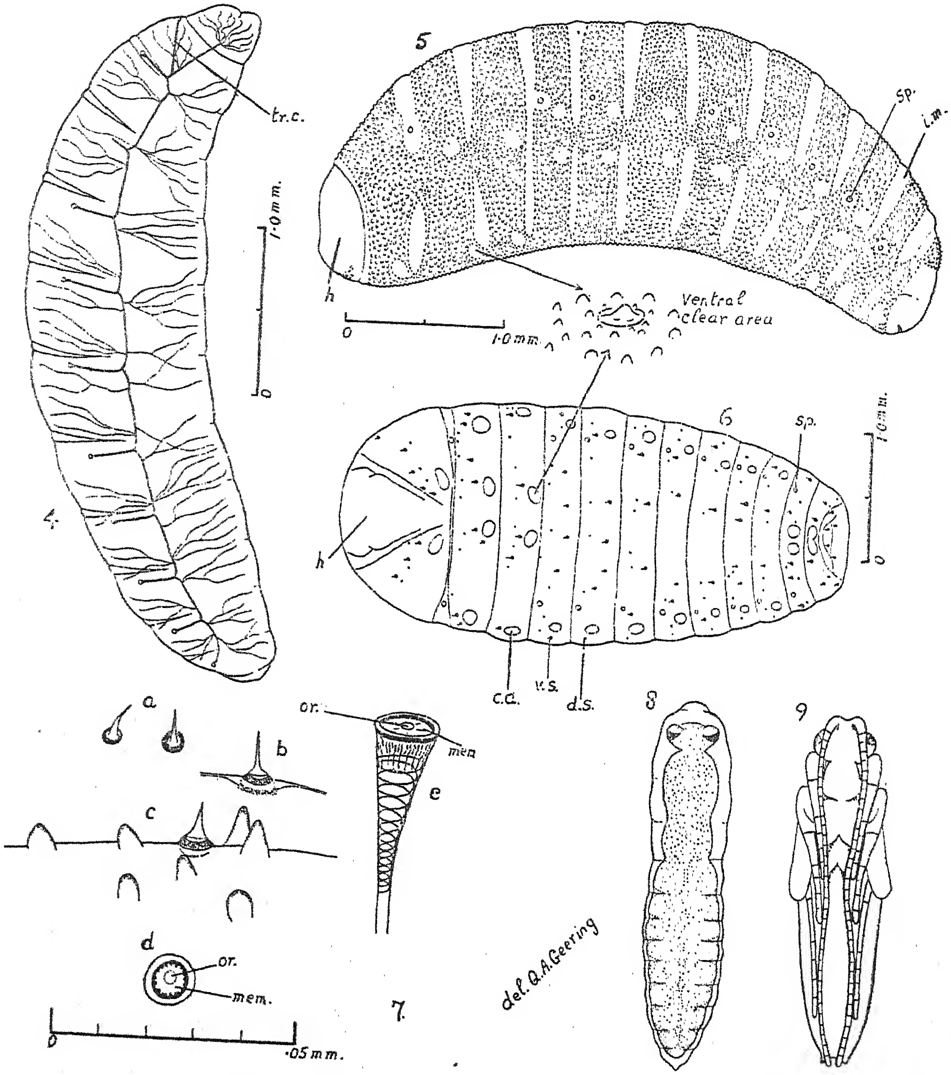
The third Instar.

This instar, measuring 1·2 mm. in length when newly formed, grows to 2·6 mm. before moulting and, compared with the previous instars, it is much longer in relation to its width. The chitinous head structures prominent in the first and second instars have here completely disappeared and only a pair of weak oral papillae are present. Fig. 3 shows the general anatomy of this instar in which the hind-gut is clearly visible opening to the exterior and has the appearance of an anal vesicle. A pair of large salivary glands run laterally from the 7th segment and join into a short common duct that opens ventrally in the labial region. The alimentary canal is composed of a short fore-gut leading into a long mid-gut which extends as far as segment ten where it ends blindly; there is also a constriction in the region of the 6th segment. The hind-gut is open posteriorly but closed where it joins the mid-gut. It is into this solid region, between mid- and hind-gut that a single pair of short malpighian tubes lead. This latter condition is very similar to that described for the honey-bee larva by Nelson (1917).

The fourth Instar.

There is a slight decrease in length when the third-instar larva moults and produces the fourth and last instar. This instar measures from 2·3 mm. to 4·5 mm. and when newly formed possesses a well-defined head and mandibles, but these and the other head structures are soft and colourless. At this time too, spiracles and tracheae are present but contain no gas. Air first appears in the tracheal system when the larva has reached about 3·5 mm. in length, at which time it is still lying in the host's body fluid. By this time the head structures, especially the mandibles, are heavily chitinised and pigmented.

When fully grown, the fourth-instar larva almost completely fills the host puparium and is enclosed within a jacket of air contained by the prepupal skin of the host. It is clearly differentiated into a head, three thoracic and nine abdominal segments. An incompletely separated tenth abdominal segment may be represented at the anal extremity and each segment is wholly or partly covered with small cuticular papillae.



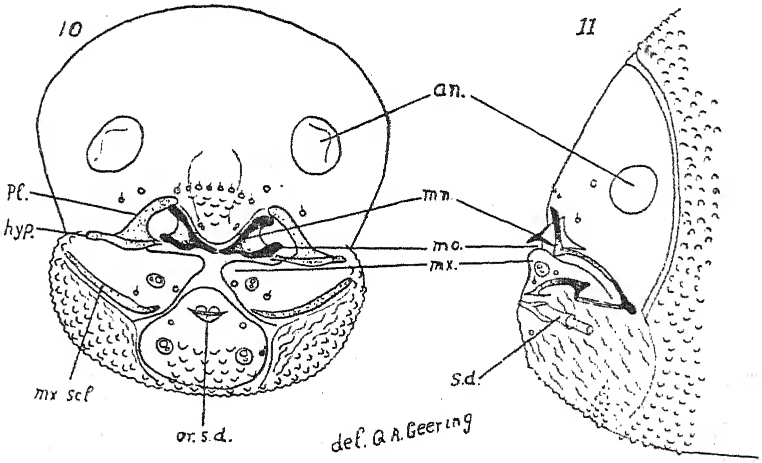
Figs. 4–9.—*D. gracilis*, 4th instar larva, pupa and prepupa. (4) tracheal system of 4th instar seen laterally; (5) lateral view of 4th instar showing areas of cuticle free from papillae; (6) distribution of setae (diagrammatic) 4th instar; (7) cuticular structures of 4th instar; a and b, setae; c, seta and papillae; d, surface view of spiracle; e, diagram of spiracle and proximal trachea. (7, a-d camera lucida); (8) prepupa; (9) pupa. c.a. area clear of papillae; d.s. dorsal seta; i.m. intersegmental membrane; h. head; mem. membrane; or. orifice; sp. spiracle; tr. c. transverse commissure; v.s. ventral seta.

Tracheal System.—It is in the fourth instar that the tracheal system, possessing nine pairs of functional spiracles, first appears. The anterior pair is situated on the membrane between thoracic segments 1 and 2; the remaining spiracles occur towards the anterior margins of abdominal segments 1 to 8, each being surrounded by an area of cuticle 68μ diam. which is free of papillae. The spiracle itself measures 13μ diam. and is almost closed by a thin membrane, leaving an orifice of $4{\cdot}5\mu$ diam.

connecting the tracheal system to the exterior (fig. 7 d & e). Each spiracle leads into a short tracheal tube directed ventrally which joins the lateral tracheal trunk. Thoracic segment 3, however, which bears no spiracle has a short, blind, tracheal tube. Fine branches of tracheae leave the main trunks and supply each segment; the lateral trunks also run into the head where they give off a rich supply of tracheoles. There is an arched transverse commisure in the first thoracic segment joining the two lateral trunks (fig. 4).

Cuticular Structures.—The cuticular papillae are bluntly conical in shape and cover each segment except for certain clear areas principally in the head, anal, intersegmental and spiracular regions. The distribution of these, and other subsidiary clear areas, are illustrated in fig. 5. Staining the larval skin with picro-aniline blue in glacial acetic acid reveals, on each segment, the presence of sharply pointed setae which take up the stain at the base and apex, in contrast to the papillae which stain only at the apex (fig. 7 a-c). These are most numerous on the anterior segments and their number and position differs from segment to segment. A ring of these setae around the anus may indicate the presence of an additional segment here, making a possible total of ten abdominal segments (fig. 6).

The Head.—The head of the fourth instar (figs. 10 and 11) protrudes slightly ventrally and is free of papillae, except for a small area below. Dorsolaterally two raised areas indicate the positions of antennae. The mandibles are large and strongly chitinised, articulating with pleurostomal and hypostomal bars. Clearly defined maxillary and labial areas are apparent with associated papillae and sensillae. The labial region, which protrudes as a large lower lip, has the salivary duct opening on to its surface.



Figs. 10–11.—*D. gracilis*, 4th instar head structures. (10) anteriorly; (11) laterally. an. antenna; hyp. hypostomal sclerite; mn. mandible; mo. mouth; mx. maxilla; mx. scl. maxillary sclerite; or.s.d. orifice of salivary duct; pl. pleurostomal sclerite; s.d. salivary duct.

The last instar of *D. gracilis* bears a close resemblance to that of *D. navicularis* var. *cynaraphyla*, except that the body segments of the latter are covered not with blunt papillae but short curved spines. When fully grown, the last instar larva passes into a quiescent prepupa in which the three regions of the head, thorax and abdomen become well-defined (fig. 8). At pupation, the last larval skin is shed, leaving an exarate pupa (fig. 9) enclosed within the host puparium. In some cases, the fully grown larva spins an incomplete cocoon inside the prepupal skin of the host.

Excretion.

All larval instars are characterised by the possession of spherical, white, opaque bodies scattered in the fat-body. These contain concretions of uric acid but their fate at pupation and afterwards is not known. The malpighian tubules do not communicate with the hind-gut until the last instar and, even at this stage, the orifice connecting the two organs appears to be minute. Throughout larval life the mid-gut is closed posteriorly and the last-instar larva does not extrude a meconium but, during pupation, the gut contents are concentrated to a small black pellet in the posterior region of the mid-gut.

Feeding of the Larvae.

The first-instar larva is enclosed by the trophamnion and it is possible that it derives its nourishment from this structure. The mouth parts are well-developed but their functional significance is not certain. In the second instar the mouth parts are again well formed and many individuals have been found attached by these to the fat-body of the host. The primordia of the testes and ovaries of the host appear to be among the first organs to be consumed as they are rarely found in parasitised larvae. Feeding in the third instar is presumably by ingesting the body fluids of the host as the mouth parts are greatly reduced. In the fourth instar the mouth parts are again well-developed and during this instar the host organs are completely devoured. In the last instar it appears possible that a certain degree of external digestion occurs as the salivary duct is placed well ventral to the mouth. This would facilitate the destruction of the host tissues and account for the rapid growth of the parasite in this stage. In the second and third instars the salivary glands are prominent but in these cases the duct opens close to the mouth.

Life-history.

D. gracilis passes through two complete generations in a year, coinciding with the two generations of its host. The winter is spent in the larval or prepupal stages in larvae or puparia of the host. Growth appears to continue throughout the winter being arrested only when the soil is frozen or nearly so. In 1944–45 the parasites in the host larvae passed the winter in the 2nd or 3rd instars, whilst those in the puparia were in the 4th instar. Prepupae were found at the end of February and pupae at the end of March. As many host larvae did not pupate until March or early April, and formation of the 4th instar of the parasite does not take place until this occurs, pupation of the parasite was very protracted and not complete until early June. In December 1945, some 50 per cent. of the parasites were already in the prepupal stage and remained so until February. With this exception the same overwintering stages were recorded as in the previous year.

Emergence.

The emergence of adults was followed by removing the adult parasites and carrot flies from fine-mesh cages erected on land carrying heavy carrot fly populations. In 1944 and 1945 records were obtained from Mepal (Isle of Ely) and Swaffham (Norfolk) for both generations, and under comparable conditions for parasite and host. The results are set out graphically in figs. 12 and 13. At Mepal in 1944, the 1st generation began emerging on 18th May and continued until 5th July. For the 2nd generation arising from plots of early sown carrots, the emergence period was 2nd to 23rd August. In 1945, which was a much earlier season, the corresponding periods of emergence for the 1st and 2nd generations were 7th May to 19th June and 20th July to 24th August respectively. The data obtained at Swaffham shows similar relationships for the two years. In all cases, the peak emergence of the parasite is later than that of the host and, with the exception of the conditions at Swaffham in 1945, this relationship also exists for the beginning of emergence. From a knowledge of the degree of parasitism on the cage sites, and the numbers of adult

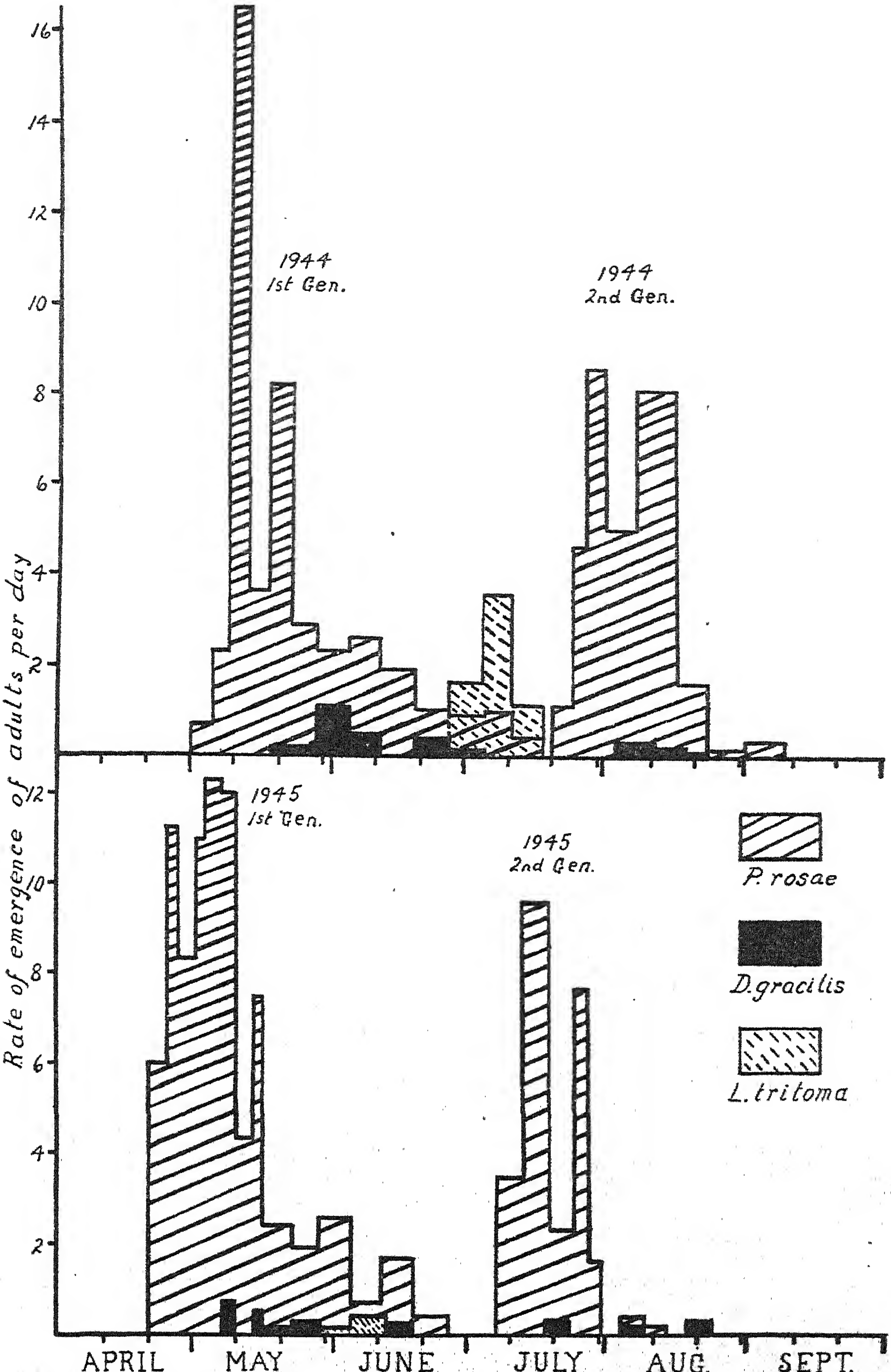


Fig. 12.—Histograms for emergence of *P. rosae* and its two principal parasites, *Dacnusa gracilis* and *Loxotropa tritoma*. Mepal 1944 and 1945.

hosts and parasites emerging, it was found that in each locality not more than 50 per cent. of the parasites which should have emerged in the cages were collected from these. This discrepancy was partly due to the difficulty of finding small insects amongst foliage but was chiefly due to the marked tendency of the female parasite to frequent holes and cracks in the soil, presumably in search of possible hosts. The emergence histograms based on field data do not, therefore, represent the emergence of total populations. The proportion recovered was, however, sufficient to show that there is a close correlation between lengths of the summer and overwintering generations with those of the host.

Sex Ratio and Behaviour of Adults.

In captivity the adults show a great tendency to creep into crevices and to escape through small holes or cracks. This capacity appears to be utilised in the field in the parasite's search for hosts, for it is most strongly marked in the females. Thus of 89 adults taken from one set of cages, 64 were males and in another set of 32 adults, 24 were males. On another occasion, 21 adults were caught crawling on carrot vegetation in the field; of these 20 were males. These figures give a misleading sex ratio and an estimate of the true sex ratio of the overwintering generation was obtained in 1945. In this instance 266 pupae gave rise to 108 males and 158 females, representing a sex ratio of very nearly 3 females to 2 males. Emergence of these occurred in an open insectary and both sexes came out over the whole period.

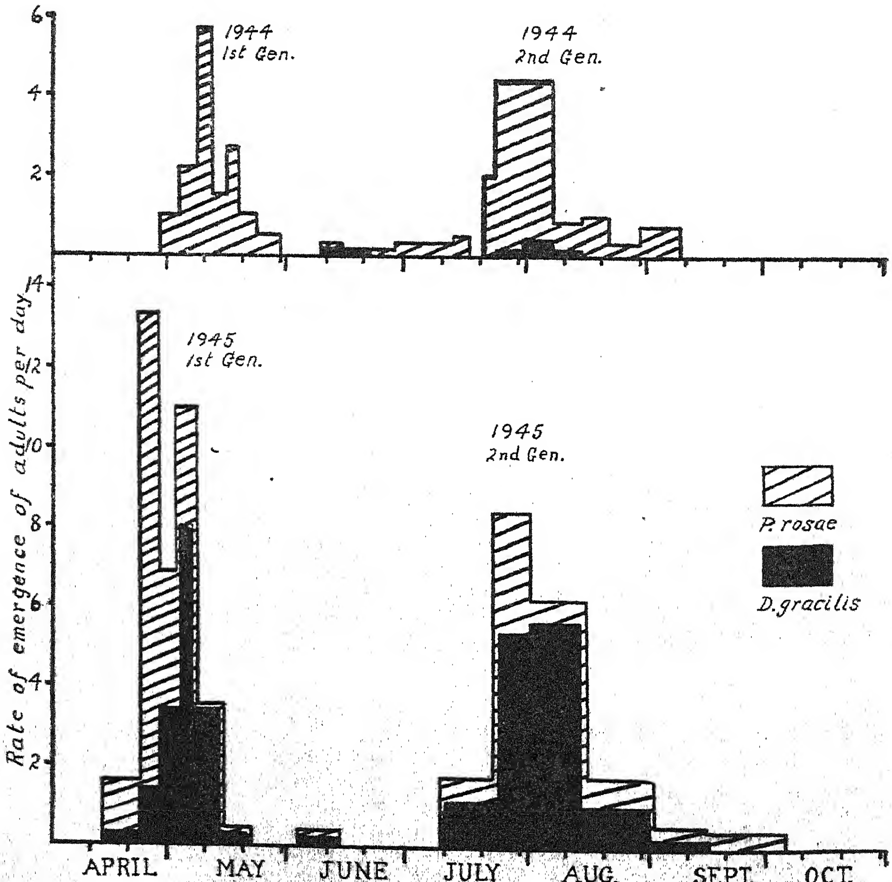


Fig. 13.—Histograms for emergence of *D. gracilis*, superimposed on similar histograms for *P. rosae* 1st and 2nd generati...

Effect on the Host.

Parasitism by *D. gracilis* markedly affects the colour and size of the host puparia· Unattacked puparia are pale-yellow or light brown in colour whilst those parasitised are nut brown. The effect on the size of the host is shown in fig. 14, where the size distribution of parasitised puparia formed in autumn and in spring are compared with unparasitised puparia of the same origin. It will be seen that for the autumn formed puparia those parasitised are smaller than those not parasitised (A). The same relationship exists for those individuals which pass the winter as larvae and pupate in the spring (B). Furthermore, those parasitised puparia which are formed in the autumn are a smaller size group than those formed in the spring (D). This latter character appears to be a reflection of the size difference existing between autumn and spring formed unparasitised puparia (C). The puparia of the summer generation, parasitised and unparasitised, are of the same size and show the same differences as those formed in the autumn.

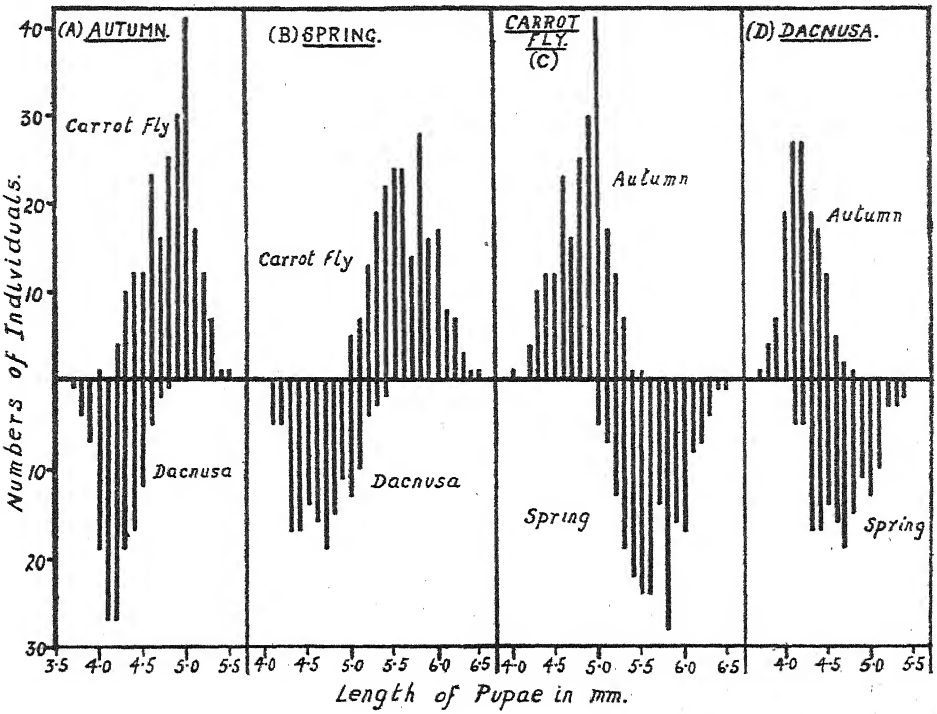


Fig. 14.—Size distribution of parasitised and unparasitised *P. rosae* puparia.
(A) Autumn-formed : Normal and parasitised.
(B) Spring-formed : Ditto.
(C). Autumn and Spring-formed : Unparasitised.
(D) Ditto : Parasitised.

Range of Parasitism.

The level of parasitism by *D. gracilis* in carrot fields and plots in East Anglia was found to vary considerably. In Table I is given an analysis of the parasitism of the overwintering carrot fly population in two fields at Mepal and two plots at Cambridge. The low parasitism in Field I is related to the age of the carrot crop. This was sown in June, and received no first generation carrot fly attack, and the recorded parasitism was therefore brought about by migrant adult parasites of the second generation. The remaining fields and plots were of early sown carrots, thus allowing host and parasite to have passed both a summer and a winter generation

TABLE I.

Analysis of Parasitism on overwintering Populations of Carrot Fly. Samples taken November and December, 1945.

Locality	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Aleochara*	Per cent. Parasitism
Mepal: Field I ...	88·5	11·5	—	—	11·5
Field II ...	78·8	20·1	1·1	—	21·2
Cambridge: Plot I ...	74·2	23·9	1·9	—	25·8
Plot II ...	78·3	21·7	—	—	21·7

TABLE II.

Analysis of Parasitism on overwintering Populations of Carrot Fly. May Plot, Mepal, 1943–44. *Sown* 1943.

Date of Sampling	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Aleochara*	Per cent. Parasitism
1944					
24th April	74·0	19·3	4·9	1·8	26·0
25th May	69·9	17·3	7·7	5·1	30·1
19th June	68·1	19·4	11·5	0·2	31·1

TABLE III.

Analysis of Parasitism. June Plot, Mepal, 1944–45. *Including larval and pupal Parasitism through the Winter.*

Date of Sampling	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Aleochara*	Per cent. Parasitism
1944					
22nd November: Larvae	94·3	5·7	—	—	5·7
Pupae	77·0	22·9	—	—	22·9
Total Population ...	86·8	13·2	—	—	13·2
19th December: Larvae	84·4	15·6	—	—	15·6
Pupae	83·9	16·1	—	—	16·1
Total Population ...	84·2	15·8	—	—	15·8
1945					
25th January: Larvae	89·3	10·7	—	—	10·7
Pupae	74·6	25·4	—	—	25·4
Total Population ...	79·6	20·4	—	—	20·4
26th February: Larvae	95·2	4·8	—	—	4·8
Pupae	76·8	22·5	0·7	—	23·2
Total Population ...	79·8	19·5	0·7	—	20·2
21st March: Larvae	87·5	12·5	—	—	12·5
Pupae	86·5	13·5	—	—	13·5
Total Population ...	86·6	13·4	—	—	13·4
20th April: Larvae	—	—	—	—	—
Pupae	79·7	19·3	—	1·0	20·3

on these. Table II shows the analysis of the total parasitism on a May-sown carrot plot, at Mepal, made in the spring of 1944 ; and in Table III is a similar analysis for an adjoining June-sown plot made in the winter and spring, 1944–45. In both years the parasitism by *D. gracilis* was similar as there was a nearby source of *D. gracilis* in 1945 which offset the lateness of sowing and absence of first generation attack. It will be seen from Table III that the level of total parasitism remained almost constant from January to April, over the latter half of which period pupation of the host was rapid. This would suggest that parasitism of the overwintering larvae was of the same order as that of the puparia and that, in the previous autumn, the larvae were parasitised regardless of their size. Parasitism of the summer generation of carrot fly is shown in Table IV. Here the data refers to five fields of early sown carrots and shows a considerable variation in incidence of *D. gracilis*. The level of attack by this parasite is, however, usually far higher in the summer generation than in the overwintering generation of carrot fly.

In the carrot-growing areas of East Anglia parasitism by *D. gracilis* is usually about 20 per cent. on the overwintering populations of the carrot fly and some 10 per cent. higher on the summer population (1st Gen.). There is, however, some evidence that under certain conditions this relationship may be changed in favour of the parasite. At Swaffham (Norfolk) a succession of carrot crops were grown on

TABLE IV.

Parasitism of Summer (1st) Generation of Carrot Fly. Early sown Carrots, Chatteris (Isle of Ely), 1945.

	Date of Sampling	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Kleidotoma*	Per cent. Parasitism
Field 1	27th June ...	80·6	18·2	—	1·2	19·4
Field 2	6th July ...	65·6	34·4	—	—	34·4
Field 3	30th July ...	75·2	13·4	11·4	—	24·8
Field 4	30th July ...	53·6	46·4	—	—	46·4
Field 5	20th August...	58·8	21·6	19·6	—	41·2

adjoining plots in 1944 and 1945. The effect of this practice on the abundance of the host and parasite over the two years can be seen in fig. 13. The records relate to adults caught in the same number of cages for each year and show that in the course of four generations the parasite increased from a very low level to a state of parity with the host. There was also a marked, although not proportionate, increase of the host. A detailed analysis of the parasitism on these plots in 1945 is given in Table V.

TABLE V.

Parasitism on Swaffham Plots—1945.

Plot	Date of Sampling	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Aleochara*	Per cent. Parasitism
1	6th February	63·6	36·4	—	—	36·4
2	13th April ...	51·8	48·2	—	—	48·2
3A	26th July ...	47·7	52·3	—	—	52·3
4B	26th July ...	44·0	56·0	—	—	56·0
5A	25th October	40·5	59·5	—	—	59·5
6B	25th October	30·5	65·2	4·3	—	69·5

In Table V, records 1 and 2 relate to the overwintering generation 1944–45, records 3 and 4 to the summer generation 1945 and records 5 and 6 to the overwintering generation 1945–46. The level of parasitism observed at the last time of sampling was not, however, sufficient to prevent severe damage to the crop by the host.

Effect of DDT Treatment on the Level of Parasitism.

In 1945, DDT treatment of carrot crops was used as a method for controlling carrot fly and observations were also made on the effect of DDT on the parasite populations.

TABLE VI.

Parasitism on DDT-treated, and untreated Carrot Crops, 1945. *Samples taken November,* 1945.

	Per cent. Normal	Per cent. *Dacnusa*	Per cent. *Loxotropa*	Per cent. *Aleochara*	Per cent. Parasitism
Mepal :					
Treated Field ...	95·0	2·5	2·5	—	5·0
Untreated Field ...	78·5	20·1	1·1	—	21·2
Cambridge :					
Treated Plot	96·2	3·8	—	—	3·8
Untreated Plot ...	74·2	23·9	1·9	—	25·8

Table VI contains data from two fields and two plots, one of each having been treated twice with a 0·5 per cent. DDT emulsion applied in July and August. In both cases the treatment brought about a marked reduction in parasitism by *D. gracilis*, a result which was expected from the field observations of Wright and Ashby (1945). In neither of these nor in other similar cases was the parasite completely eliminated but the treatment effected, as with carrot fly, a considerable reduction in the population. A second parasite, *Loxotropa tritoma*, Thoms., was not affected as the DDT was applied after the flight period of this parasite (*vide infra*). The adult forms of *D. gracilis* are adequately described by Nixon (1937) and no description is included here.

Loxotropa tritoma, Thoms.

L. tritoma belongs to the family Diapriidae of the Proctotrupoidea. The little information available on this group of insects indicates that they are all parasites of Dipterous larvae or pupae. The genus *Loxotropa* (Foerster) is of world-wide distribution and Imms (1930) has summarised its distribution. Hosts have been recorded for only four species of the genus, one in England and three abroad. Kloet and Hincks (1945) give a list of 27 species occurring in Britain.

Hosts of L. tritoma.

L. tritoma has been recorded parasitising *Oscinella frit*, L., in Germany, Switzerland and Russia, and in England at Harpenden by Imms (1930) who recorded 2 per cent. of the frit fly population attacked by this parasite. Mr. Nixon of the Imperial Institute of Entomology, who kindly identified the specimens reared from carrot fly, has compared these with adults reared from frit fly by Imms and Perkins. He found no differences between the adults and on morphological grounds they can be regarded as the same species. There are, however, certain biological differences

between the parasites reared from the two hosts which are worth recording. When attacking carrot fly *L. tritoma* passes through only one generation a year, emergence occurring between 29th May and 27th June towards the end of the emergence of the first generation of carrot fly. When a parasite of frit fly, however, *L. tritoma* apparently passes through at least two generations a year, the second emergence of adults occurring from 5th to 19th August (Imms) at the end of the second emergence of frit fly. A further difference is that when parasitising carrot fly *L. tritoma* enters into a diapause in July when in the first larval instar and remains as such until the following spring. Dr. Imms informs us that he found no evidence of a diapause occurring when the parasite attacked frit fly.

At present, no further conclusions concerning the identity of the two types can be drawn from these facts. Other differences may appear when both the conditions under which *L. tritoma* attacks frit fly, and its immature stages, in this host are studied. For the present, any observed differences in its biology may be regarded as an adaptation of the parasite to different hosts.

Meier (1930) records *Chloropisca notata*, Mg., as a host for *L. tritoma* in Russia.

Life-history.

L. tritoma passes through one generation in a year on the carrot fly. The adults emerge towards the end of the emergence period of the 1st generation of the carrot fly, the time varying with the earliness of the season. In fig. 12 is shown the emergence periods for 1944 and 1945 at Mepal. In 1944 the emergence occurred from 27th June to 18th July and in 1945 from 29th May to 12th June some three weeks earlier than the previous year. It is assumed that the females, after pairing, attack the carrot fly larvae probably in their final instar. In July the parasite is found in the first instar within the pupa of the carrot fly. It remains in this condition until the following spring when it completes its metamorphosis.

Sex Ratio.

Males and females occur in approximately equal numbers. In one set of 25 individuals reared in the insectary 13 were males and 12 were females. The emergence of both sexes was equally distributed over the whole emergence period.

The Adult.

The adults of *L. tritoma* are small and black, measuring about 2 mm. in length (excluding the antennae), with a wing-span of 3·5 mm. Imms (1930) gives adequate descriptions of both sexes where the chief difference appears in the antennae; those of the female are clubbed while in the male they are filiform.

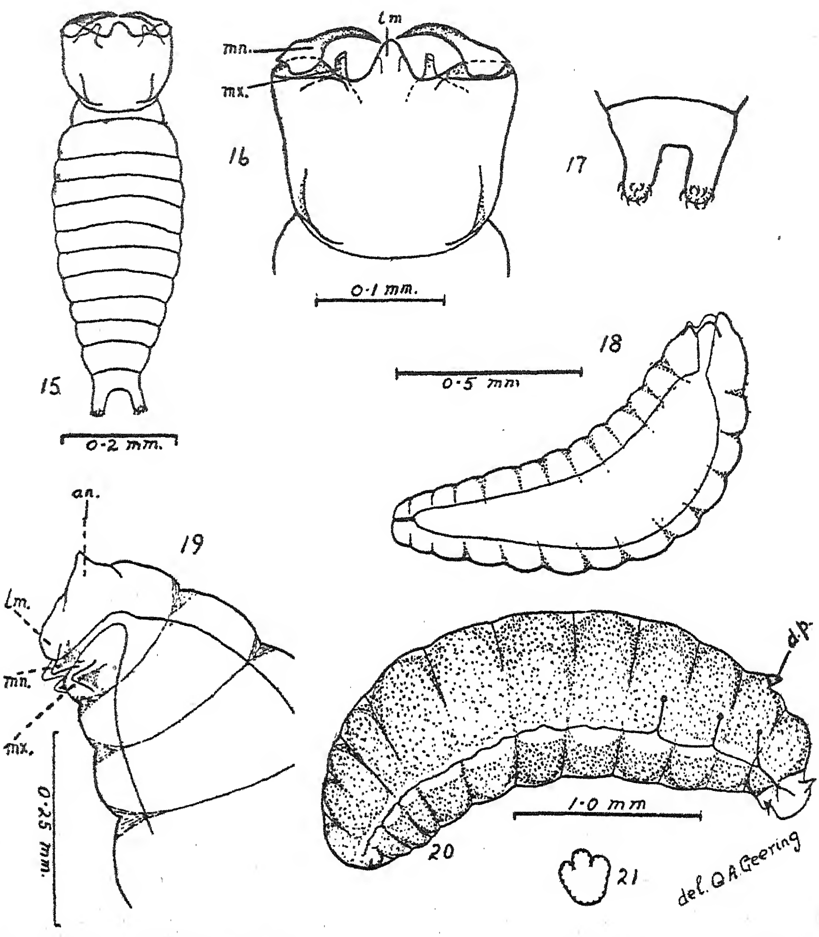
The larval Instars.

L. tritoma passes through three larval instars prior to pupation. There is a brief prepupal stage and pupation takes place within the host puparium.

The first instar is typical of the Diapriidae. It measures 0·48 mm. long by 0·15 mm. at its widest point and grows to 1·0 mm. by 0·3 mm. before ecdysis. The head-capsule is strongly chitinised and flattened dorsoventrally; it is almost square and measures 0·13 mm. in length by 0·16 mm. in breadth. The head also bears a pair of strong, curved, mandibles which measure 0·077 mm. and articulate with the anterior border of the head capsule. The body, consisting of 12 segments, broadens to the fifth and sixth segments, then narrows to the twelfth segment which bears two lateral protruberances each armed with 16 small hooks. The gut is blind posteriorly and contains some of the brown contents of the disintegrated host pupa. There is no tracheal system in this instar.

The second instar measures 1·2 mm. by 0·4 mm. when newly formed and grows to 2·4 mm. by 0·7 mm. It is a vermiform hymenopterous type of larva with a

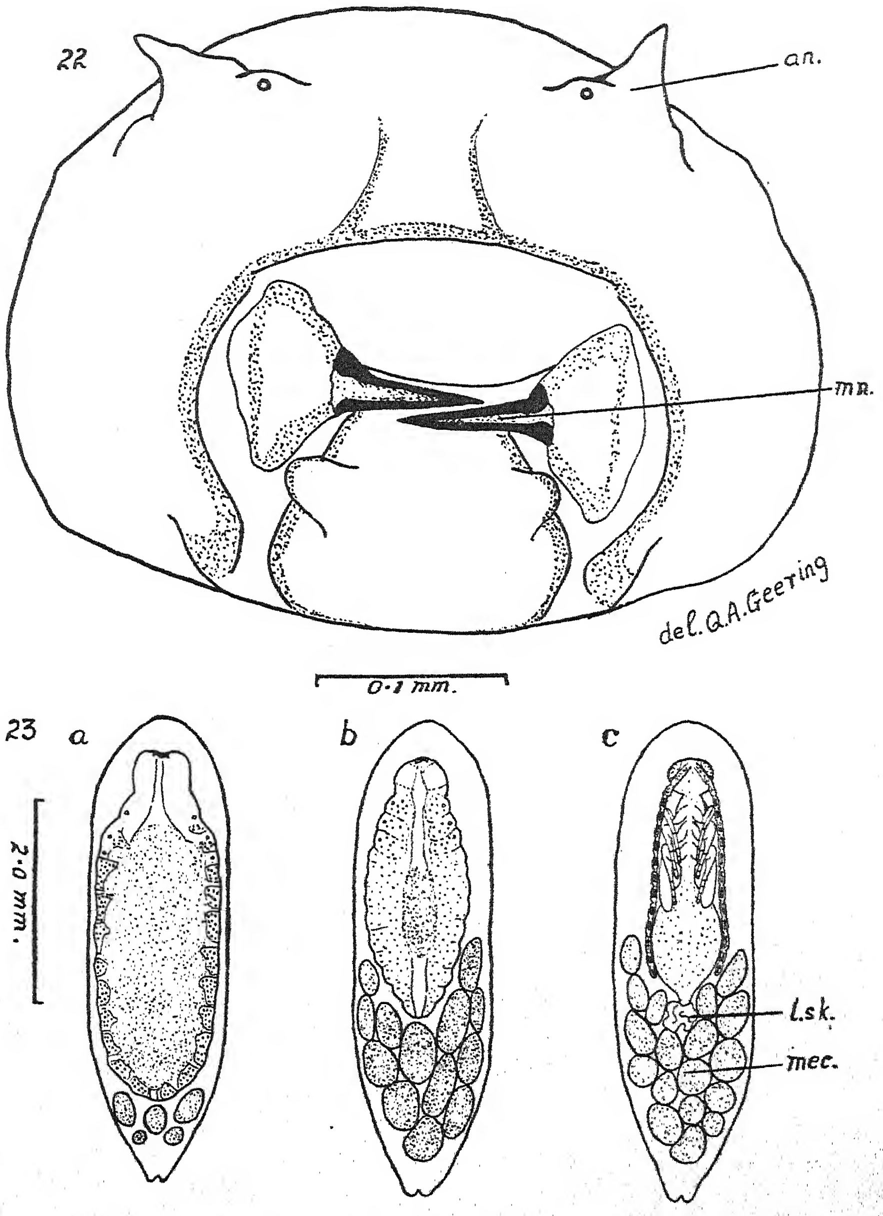
poorly developed head in which the only conspicuous structures are a pair of conical antennae. The mouth-parts consist of weak, fleshy, lobes with an upper lip separated from the mandibular and maxillary lobes. There are no other appendages and no tracheal system is apparent. The colour is of a pale chocolate-brown, produced by the contents of the gut which almost completely fills the body-cavity.



Figs. 15–21.—*Loxotropa tritoma.* (15) 1st instar, fully grown; (16) detail of head capsule; (17) 1st instar, 12th segment; (18) early 2nd instar; (19) fully grown 2nd instar, anterior region; (20) 3rd instar, fully grown; (21) spiracle of 3rd instar. an. antenna; d.p. dorsal papilla; lm. labrum; mn. mandible; mx. maxilla.

The third and final instar grows from 2·5 mm. by 0·8 mm. to 3·5 mm. by 1·0 mm. and when fully grown occupies the whole of the interior of the host pupa. It is slightly flattened dorso-ventrally and the cuticle is entirely smooth. Three pairs of spiracles occur and these are on the second and third thoracic segments and the first abdominal segment, and are trifoliate in shape. They are connected by a lateral tracheal trunk which extends to the posterior segment of the body. The dorsal surface of the second thoracic segment bears a pair of short pointed papillae. The head is short and sub-spherical and possesses pointed antennal lobes and a pair of very prominent mandibles each measuring 0·08 mm. in length. These are

dark brown and strongly chitinised, with broad triangular bases. Small maxillary lobes are also present. When fully grown this larva has completely ingested the contents of the host pupa and possesses the same brown colour shown by these. The gut again fills almost the whole of the body cavity.



Figs. 22–23.—*L. tritoma* (22) head of last larval instar; (23) changes during pupation; a, 3rd instar larva commencing to extrude gut contents; b, same process almost complete; c, pupa and meconium within host puparium.
an. antenna; mec. meconium; mn. mandible; l.sk. shed skin of 3rd instar larva.

Pupation.

The process of pupation is preceded by a very considerable change in size of the final instar larva. This is caused by the voiding of the entire contents of the gut. When fully grown this instar measures 3·0 to 3·5 mm. by 1·0 mm. In the laboratory, carrot fly pupae with larvae of *L. tritoma* in this stage were placed in an incubator, the temperature of which varied from 15° to 20°C.; the puparia were in moist sand. After 4 days the larvae commenced to excrete the gut contents and under these conditions the process was complete within 24 hours, after which time the larva or prepupa measured 1·5 mm. by 0·7 mm. The meconium was in the form of numerous, irregular, ovoid pellets similar in colour to the gut contents before their extrusion. The number of pellets varied from 100 to 150 and the size ranged from 0·08 mm. to 0·29 mm. in diameter. Each pellet appeared to be a discrete object enclosed within an extremely thin membrane whilst the whole mass of pellets was enclosed in a second very thin, but strong, membrane. The process of extrusion of the gut contents was accompanied by shrinkage of the anterior region of the body and when the gut was empty the larva appeared much shortened, shrivelled, and of an opaque white colour. Following this the larval skin was shed, leaving an exarate pupa measuring 1·8 mm. by 0·6 mm. with the last larval skin adhering to the posterior end. The posterior half of the pupa was surrounded by the excretory pellets which completely filled the remaining, and larger, space of the host puparium. The changes incurred during pupation are illustrated in fig. 23 a, b and c.

The duration of the immature stages in the field are shown in Table VII. The bulk of the life-cycle is occupied by the 1st instar larva which persists for some 8 months. The two remaining larval instars together require about one month for their development, as do also the prepupal and pupal stages. The length of life of the adult in the field is not known but, under laboratory conditions, they were kept alive for 10 days.

TABLE VII.

L. tritoma.—*Duration of Larval Stages in the Field. Mepal (Isle of Ely).*

Date	Instar	Duration in Days
July, 1944	1st	250
24th February, 1945 ...	1st	
22nd March, 1945... ...	2nd	18
9th April, 1945	2nd	
18th April, 1945	3rd	12
21st April, 1945	3rd	
24th April, 1945	3rd	
30th April, 1945	Pupation	30
10th May, 1945	White pupa	
14th May, 1945	White pupa	
29th May, 1945	Black pupa	
30th May, 1945	Emergence	

The adults possess strong 3-toothed mandibles which they use to bite a hole in the side of the host puparium at its anterior end and through this the adult emerges, one only having developed in each host.

Effect on the Host.

Carrot fly puparia parasitised by *L. tritoma* are readily recognised by their smoky-yellow colour. This effect is produced by the pale brown contents of the host pupa

in the normally coloured, pale yellow, puparium. The host contents are disintegrated and consist of a mass of oil droplets and brown granules. Microchemical tests also showed that the voided meconium of the parasite contained fat globules as well as small concretions, probably of uric acid. In size the parasitised puparia are similar to those of the first (summer) generation. Parasitism appears to occur too late in the life-cycle of the larva to affect further growth.

Distribution.

L. tritoma appears to be widely distributed in East Anglia, having been found at Cambridge, Swaffham and Chatteris (Isle of Ely). Its incidence in these localities is recorded in Tables I–VI ; in all cases the highest parasitism occurred in the Chatteris area. In each area, however, its distribution varies considerably from field to field. This appears to be connected with the availability of the host at the time (June) when the adult parasites are emerging. Thus, carrots sown after the end of May incur little first generation carrot fly attack and hence maintain through the winter few or no individuals of *L. tritoma*. The very different parasitism occurring on May and June sown carrots on adjoining plots can be seen from Tables II and III. The adult parasites are shelter-seeking insects and are not strong fliers, both of which features would tend to produce an irregular distribution in any area.

Hyperparasitism.

In addition to behaving as a primary parasite of the carrot fly, *L. tritoma* also occurs as a hyperparasite of *D. gracilis*. In Table VIII the incidence of hyperparasitism in the overwintering population is shown. It will be seen that where primary parasitism by *D. gracilis* is lowest the hyperparasitism by *L. tritoma* is also lowest and *vice versa*. Above a certain percentage parasitism by *D. gracilis* (approximately 20 per cent.) the degree of hyperparasitism appears to be directly proportional to the percentage of *D. gracilis* present. Below this level, both parasites have been found in the same population without overlapping. The data also indicates that the degree of hyperparasitism is proportional to the population of *L. tritoma* present. This evidence suggests that *L. tritoma* treats the whole population, viz. normal carrot fly and those already parasitised by *D. gracilis*, as a unit and that hyperparasitism occurs quite fortuitously.

TABLE VIII.

Incidence of Hyperparasitism by L. tritoma *in overwintering Carrot Fly Populations,* 1945.

Per cent. *D. gracilis*	Per cent. of *L. tritoma* in *D. gracilis*	Per cent. *L. tritoma*	Per cent. of *D. gracilis* with *L. tritoma*
17·3	16·8	7·7	8·2
18·7	16·6	10·8	8·7
19·7	18·1	9·3	9·0
23·9	25·0	1·9	2·0
31·0	40·0	8·5	11·1
65·0	100·0	4·3	6·6

Diapause of the first-instar Larva.

As has already been mentioned, *L. tritoma* develops as far as the first instar by early July and remains in this condition until the following spring. This arrest of growth does not appear to be directly caused by unfavourable soil temperatures, for fen soil in July and August has a daily mean temperature of between 18 and 20°C.

at a depth of 4 inches, whilst in April and May when growth recommences the corresponding soil temperatures are normally between 12 and 14°C. Since these facts suggested that during the summer *L. tritoma* enters into a diapause while in the first instar, it was decided to investigate the effect of low temperatures on this state of arrested development. Accordingly a quantity of puparia containing first-instar larvae of *L. tritoma* were collected at Mepal in early September and placed in moist sand at various constant temperatures. The treatments carried out were as follows :—

1. Constant temperature of 15°C. for 4 months (1st September–31st December).
2. Constant temperature of 5°C. for 4 months (1st September–31st December).
3. Constant temperature of 5°C. for 2 months (1st September–31st October), followed by 15°C. for 2 months (1st November–31st December).
4. Constant temperature of 1°C. for 4 months (1st September–31st December).
5. Constant temperature of 1°C. for 2 months (1st September–31st October), followed by 15°C. for 2 months (1st November–31st December).
6. Constant temperature of 15°C. for 2 months (1st September–31st October), followed by 1°C. for 2 months (1st November–31st December), followed by 15°C.
7. Constant temperature of 1°C. for 4 months (1st September–31st December), followed by 15°C.
8. Constant temperature of 5°C. for 4 months (1st September–31st December), followed by 15°C.

It will be seen that, with the exception of treatments 2 and 4, all the material was eventually brought up to 15°C. and the results at this temperature are shown in Table IX :—

TABLE IX.

Effect of low Temperature on the Diapause of L. tritoma *while in the first-larval Instar. Cambridge,* 1945–46.

Date of Examination	Treatments 1	3	5	6	7	8
1st November	1st instar	1st instar	1st instar			
15th ,,	,,	3rd instar	1st instar			
22nd ,,	,,	Pupa	Prepupa			
14th December	,,	Adult	—			
22nd ,,	,,	Adult	Adult emerged			
31st ,,	,,		Adult emerged			
1st January	,,			1st instar	1st instar	1st instar
6th ,,	,,			,,	,,	,,
12th ,,	,,			,,	2nd instar	Pupa
5th February	,,			Pupa	Pupa	
21st ,,	,,				Adult emerged	

Treatments 2 and 4 have been omitted from the table since, as in treatment 1, no change in size or development occurred at these temperatures.

The results show that under favourable temperature conditions the first-instar larva does not develop further unless it has been first subjected to a period at a low temperature. In order to break the diapause a period at 1 or 5°C. appears to be equally satisfactory; but the minimum time required at these temperatures, and the maximum temperature, that will break the diapause have not been determined. Biologically the phenomenon may be regarded as a means of surviving adverse conditions such as would be encountered during the winter.

Aleochara sparsa, Heer.
A. succicola, Thoms.
A. pernigra, Sch.

Distribution.

In all the carrot areas sampled in East Anglia, *A. sparsa* has only been found parasitising carrot fly at Mepal in the Isle of Ely. This parasite was first recorded in the spring of 1944 on a plot of May-sown carrots when all three larval stages were found. In common with other members of this family the larvae feed ectoparasitically on the pupa but enclosed within the host puparium, a condition identical with that described by Wadsworth (1915) for *A. bilineata,* Gyll., a parasite of the cabbage root fly, *Chortophila brassicae,* Bch.

Table II shows the percentage parasitism obtained for this insect. It never rose much above 5 per cent. and it is assumed, in view of the sudden drop in numbers on 19th June, that by that date the majority of larvae had left the host puparia to pupate in the soil. In the spring of 1945 larvae of this parasite were found on only one occasion—on 20th April and in very small numbers.

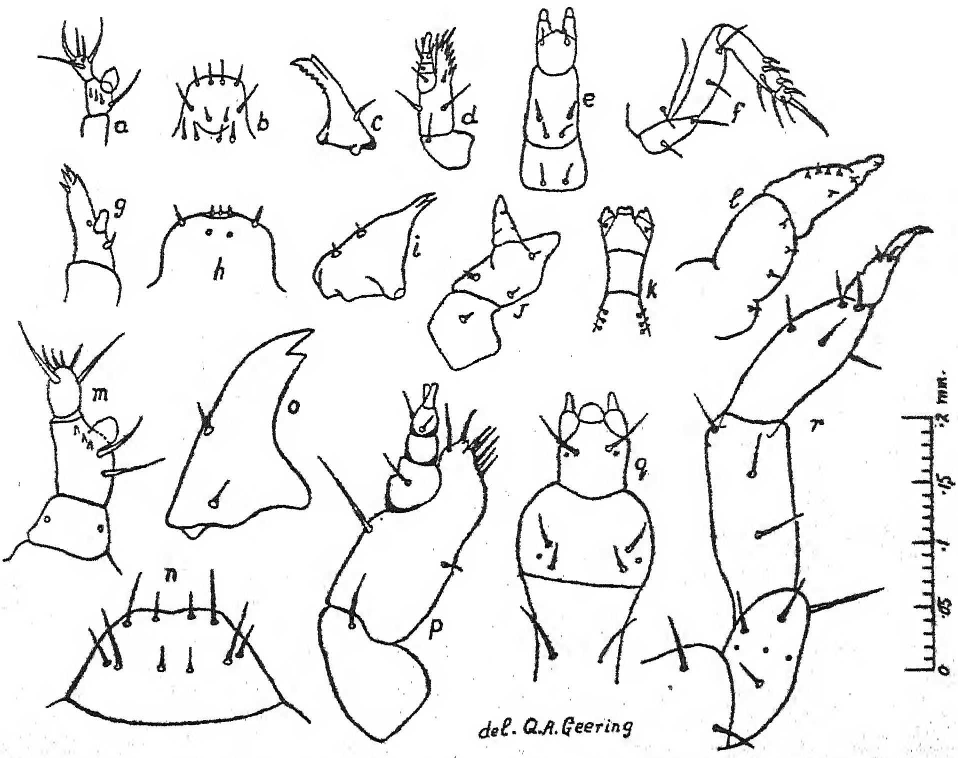


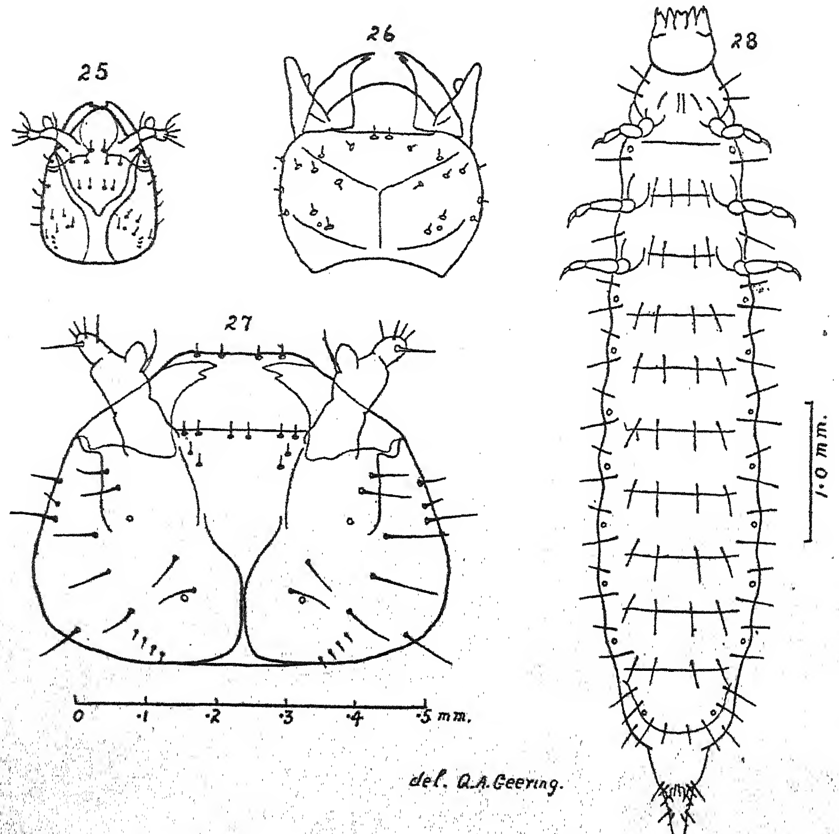
Fig. 24.—*A. sparsa.* Appendages of the three larval instars (camera lucida). a–f, antenna, labrum, mandible, maxilla, labium, leg of 1st instar; g–l, ditto 2nd instar; m–r, ditto 3rd instar.

No figures have been obtained for emergence in the field and hence it is not known through how many generations *A. sparsa* passes each year. Only one adult has been successfully raised in the insectary and this specimen emerged on 13th June. It was identified as *A. sparsa* by Mr. C. H. Tottenham of the Zoology Department, Cambridge.

The adult is a typical small black Staphylinid and measures about 4·0 mm. by 1·0 mm. It is distinguished by the lack of punctuation on the elytra. The original description by Heer occurs in "Fauna Coleopterorum Helvetica" I (1839) and Fowler and Donisthorpe (1913) differentiate *A. moesta*, Grav., which is often confused with *A. succicola*, Thoms., the latter being synonymous with *A. sparsa*, Heer. A more recent description of the adult is given by Portevin (1929).

The larval Instars.

Three larval instars have been found within puparia of the carrot fly. When the third-instar stage is reached, the cast skins of the two previous instars are found together with the fully grown larva. These all possess a well-defined head, three thoracic and ten abdominal segments. Nine pairs of spiracles occur; the first is situated on the mesothorax, the remainder are on abdominal segments 1–8. The head structures and legs show marked differences in the three instars; these are illustrated in fig. 24. The principal feature of metamorphosis is the simplification of the appendages, including the legs, in the second instar. This is very noticeable



Figs. 25–28.—*A. sparsa*, larval instars. (25) head capsule of 1st instar, dorsally; (26) ditto, 2nd instar; (27) ditto, 3rd instar; (28) ventral view of fully grown 3rd instar.

in the head structures and the head-capsules of all three instars are shown in figs. 25–27 where the chaetotaxy of the dorsal surfaces is also included. The complete drawing of the third instar larva shows the positions of only the principal setae (fig. 28).

The first instar possesses the characters of an active campodeiform type of larva and, when fully grown, measures 1·4 mm. by 0·23 mm. The head capsule is strong, elongated and pigmented (fig. 25) with heavily chitinised, curved, mandibles. These measure 0·09 mm. in length and 0·05 mm. across the base and, apically, each mandible bears a large tooth whilst the inner edge possesses a row of seven smaller teeth. The antennae, labrum and maxillae are all well-developed and bear prominent setae. The legs are also well formed, bearing a long sharp claw terminally. The whole body is covered with a strong, slightly pigmented, cuticle and large strong setae occur on all segments.

The second instar exhibits the hypermetamorphosis characteristic of this group of insects. The cuticle of the head and body is thin and transparent, the setae are short, poorly developed, and with comparatively large bases. The mandibles, measuring 0·14 mm. by 0·08 mm. are prominent but hardly chitinised and possess two slender teeth at their apices. The other head appendages and the legs are similarly reduced in complexity. All the characters of this instar show, in fact, a degeneration consequent on the parasitic habit. This larva grows to 4·0 mm. by 0·78 mm. before ecdysis.

The third instar shows again characters similar to those of the first instar. The cuticle is strong and slightly pigmented and bears large strong setae. The legs are again well-formed and possess a large terminal claw. The head-capsule is wider than long and is dark brown and heavily chitinised. The mandibles, also heavily chitinised, possess two prominent teeth apically and measure 0·20 mm. by 0·12 mm. The antennae, maxillae and labium again show the complexity apparent in the first instar. The largest individual of this stage measured 6·0 mm. by 1·2 mm.

Apart from the adult, these are the only stages that have been encountered. Thus no description of the egg or pupa can be given.

A. sparsa attacks carrot fly puparia irrespective of whether they are normal individuals or already parasitised. Thus, of the 47 specimens (of *A. sparsa*) present in the sample of 25th May (Table II), 39 were in normal carrot fly puparia and 3 were in puparia containing larvae or pupae of *D. gracilis*. The remaining 5 specimens were killed by fungus attack. Thus *A. sparsa* also is a hyperparasite of *D. gracilis*. No larvae of *A. sparsa* have been found attacking puparia containing *L. tritoma*; whether this is a chance occurrence, or an active avoidance of these puparia, is not known.

Summer Occurrence.

No samples of puparia were examined of the summer (first) generation of carrot fly in 1944. In 1945, however, extensive areas of carrots were sampled and first generation puparia examined: in none of these was any stage of *A. sparsa* recorded.

Other insect Parasites.

One other parasite has been encountered in addition to those referred to above. This was a species of Cynipoid which was identified by Mr. Kerrich of the Department of Zoology, Manchester, as belonging to the genus *Kleidotoma*, of the Eucoilinae. The species has not yet been definitely ascertained. A few adults, all females, emerged in the insectary from 26th to 30th August. Puparia containing pupae of this parasite were found in only two localities and on both occasions occurred in very small numbers, being not more than 1 per cent. of the population.

Discussion.

A study of its parasites has shown that the carrot fly has struck a favourable balance with these natural restricting agencies and that, although parasitism is occasionally heavy, it is never sufficiently high to imperil the survival of the carrot fly populations.

The plots at Swaffham have shown that by using unorthodox methods of cultivation the chief parasite, *D. gracilis*, may become very abundant but even here the level of parasitism was not sufficient to prevent serious damage to the carrot crop.

The firm establishment and wide distribution of *D. gracilis* in all the carrot fly populations studied would indicate that a relatively stable equilibrium has been reached between the parasite and its host. To change this in favour of the parasite would necessitate either the liberation of great numbers of the parasite or a change in cultural practice favouring the parasite. The latter would appear difficult to carry out, while the former would almost certainly be uneconomical since the effect would be temporary, the parasitism returning to its present natural level within a year or so.

The question of the identity of *L. tritoma*, and its behaviour on different hosts, suggests the necessity of using biological as well as morphological characters in systematics. It also indicates further lines of useful and interesting investigations into the biology of this parasite.

Acknowledgements.

In conclusion the authors wish to thank the Agricultural Research Council for providing a grant which enabled this work to be carried out, and Mr. F. R. Petherbridge for helpful advice and criticisms. Thanks are also due to Mr. G. E. J. Nixon for examining and identifying material of *L. tritoma* and *D. gracilis*; also to Mr. C. H. Tottenham for identifying material of *A. sparsa* and Mr. G. J. Kerrich for examining that of the *Kleidotoma* sp.

Summary.

Four insect parasites of the carrot fly have been encountered and of these three have been identified as *Dacnusa gracilis*, *Loxotropa tritoma*, and *Aleochara sparsa*. The fourth is a member of the genus *Kleidotoma*, species not yet ascertained.

The life-history, development and host relations of *D. gracilis* and *L. tritoma* are given together with data on their distribution and range of parasitism.

L. tritoma also occurs as a hyperparasite of *D. gracilis* but this appears to be quite fortuitous.

Experimental evidence is brought forward to show that the first instar larva of *L. tritoma* goes into a diapause in early July, that a period at a low temperature is necessary to break this and hence development is only completed in the following spring.

A description is given of the three larval stages of *A. sparsa*.

Brief reference is made to the *Kleidotoma* sp. which appears to be of rare occurrence.

The effect of DDT spraying of carrots reduces the incidence of *D. gracilis* but, when used only against second generation carrot fly attack, *L. tritoma* is unaffected.

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PHYSIOLOGICAL AND ECOLOGICAL STUDIES ON THE SPECIES OF *CAPNODIS* IN PALESTINE (COL., BUPRESTIDAE). IV. TOXICOLOGICAL STUDIES.

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The following discussion is devoted chiefly to toxicological studies, but in order to make the picture more complete, other methods of control of *Capnodis* and their practicability in the light of the studies presented in three earlier papers will first be referred to briefly.

Cultural Methods.

Collection of Adults.

The combing of the groves for adult beetles has been practised by agriculturists in Palestine in a variety of ways for many years. The best time to locate the beetles is in the early morning when they are feeding and less active, their presence often being indicated by fresh leaves on the ground. The adults may be found all the summer, but are rare in the winter.

Protective Covering.

Mr. P. Jolles of the Government Plant Protection Service suggested dry sand as a protective covering around the tree in view of the fact that the larvae cannot penetrate dry sand. The success of this method depends upon the cost and on how long the sand can be kept dry, and prevented from mixing with the soil.

Worming.

The uncovering of the root crown of the tree over an area of about 60 cm. in diameter, and scraping the roots in search of frass and larvae, has been in practice in Palestine for many years. The custom was, and in some places still is, to carry this out twice a year, once in the spring to kill overwintering larvae, and once in the autumn to kill larvae which had developed during the summer. This has been the most important method of prolonging the lifetime of a grove but scraping the roots with a knife or spade is injurious and costly, especially when each tree, whether infested or not, is treated. Furthermore, even a trained observer will not find all the larvae, and consequently a tree often remains infested after all. It was, therefore, felt that this should be replaced by a more effective and less expensive method.

Irrigation.

In an earlier paper (Rivnay 1945, p. 117) it was pointed out that moisture may kill considerable numbers of eggs and larvae. Farmers also state that in those regions where irrigation has been installed, the *Capnodis* menace has greatly decreased. Many of the stone fruit plantations in Palestine are, however, in the hills where irrigation cannot be practised.

Parasites.

Sarcophila latifrons, Fall., was reared from beetles captured in the field. The adult flies larviposit on the adult beetle selecting a soft membraneous spot such as that between the head and prothorax through which the larva enters into the body of the host immediately. Within two or three weeks the larva matures and pupates. Female beetles, when parasitised, fail to lay eggs.

The percentage of parasitised beetles is, however, quite small and, because only adult beetles are parasitised, little benefit can be expected from these flies.

Chemical Methods.

The work of Snapp (1936 and 1938) against the peach borer in the United States on the use of ethylene dichloride led entomologists in Palestine to try it against *Capnodis* larvae. Dr. K. Shweig of the Government Plant Protection Service carried out a series of experiments in the Esdraelon Valley in which applications were made to the trees and the results assessed by uncovering the roots and digging out the larvae. With the kind consent of Dr. Shweig, some of his results will be quoted below for comparison with the work of the present writer, who carried out tests in the coastal plain by a laboratory method. Ethylene-chlorhydrin, ethylene-bromhydrin, and ethylene-dibromide were tested in addition to ethylene-dichloride.

The method of applying the insecticide directly to the tree, which is the usual procedure, has disadvantages for experimental purposes. In the first case a new and unknown substance cannot be applied freely lest it prove detrimental to the tree. Secondly, a sufficiently large number of trees cannot be obtained for experimental purposes. Thirdly, not every tree is infested, so material and time may be wasted on several trees which will yield no information. Fourthly, in case of failure, no exact information can be derived as to the cause of such failure. Consequently the writer carried out toxicological studies on larvae breeding in pieces of wood.

Small sections of almond branches from 15–20 cm. long and from 3–6 cm. in diameter were used as food and breeding places for the *Capnodis* larvae. The neonate larvae were placed in small slits in the bark of the wood and permitted to grow for 4–8 weeks by which time they were sufficiently large for the requirements of the experiment.

The infested wood sections were tied in bundles and buried in the ground at a depth of 25–30 cm., and the insecticide applied to the surface of the soil. Three to five days later, the bundles of wood were uncovered, the bark peeled off and the mortality of the larvae assessed. In order to facilitate the location and recovery of the bundles, each was tied with a wire sufficiently long for its free end to be left visible above the surface of the ground. Any number of tests could be made on the larvae in this way and it enabled the distance to which the gas was effective to be measured and many other questions to be studied. The effects of treatment had, of course, to be tried out on healthy trees, separately, before any recommendation to the farmers could be made.

Ethylene Chlorhydrin.

This substance is soluble in water and can be diluted easily.

Eight bundles of infested almond sections were buried in the ground at a depth of from 25–30 cm. in the form of a cross. Four bundles were from 15–20 cm. from the centre each, and four were about 50 cm. from the centre each. After they were properly covered with earth, 80 ml. of ethylene chlorhydrin was poured into a hole in the centre. Four days later the bundles were uncovered, the bark peeled off, and the larval mortality assessed. Twenty-two larvae in the inner bundles were alive, and three were dead whilst 25 in the external bundles were alive and three were dead.

These results showed that ethylene chlorhydrin, under such circumstances, had little insecticidal value and it was no longer used for experimental purposes.

Ethylene Dichloride.

In a preliminary experiment ethylene dichloride proved to be a stronger insecticide than ethylene chlorhydrin, and consequently a series of experiments were

carried out with it in 1939, the results of which are detailed in Table I. The aim was to elicit the following information :—

(*a*) The amount of ethylene dichloride required for a certain area ;
(*b*) The distance to which the fumes would penetrate and kill *Capnodis* larvae ;
(*c*) The most effective method and form of application.

In these experiments, the bundles of infested wood sections were buried in the ground at a depth of 30 cm. Twelve bundles were used in each experiment arranged in the form of a cross as follows : four within a radius of 20 cm. ; four within a radius of about 35 cm., and four at a radius of about 50 cm.

Application was made in two ways with dosages of 60 cc., 100 cc., 120 cc. and 150 cc. In one method the entire dose was poured into a hole 5 cm. deep in the centre of the area, in the other, it was divided into four parts, and each part was poured into a hole between the arms of the cross at a radius of about 40 cm. The bundles were left in the ground for four or five days, and then removed and the mortality counted. The results are given in the following Table I :—

TABLE I.

Fumigation Experiments with Ethylene Dichloride against Capnodis *Larvae.*

A.

Dose applied in the centre of the area.

Date	Quantity applied	Mortality at 15–20 cm.		30–35 cm.		50–55 cm.		75 cm.	
		dead	alive	dead	alive	dead	alive	dead	alive
12.viii.38	150 cc.	24	0	29	0	8	8		
21.xi.38	150 cc.	29	0	14	1	5	5	4	9
21.x.38	120 cc.	26	0	21	1	7	6		
21.xi.38	120 cc.	19	0	12	0	4	32		
12.viii.38	100 cc.	62	0	23	13	8	96		
21.xi.38	100 cc.	39	0	20	0	8	9		
8.ix.38	60 cc.	12	0	2	0	0	16		

B.

Dose divided equally between four holes in the area.

Date	Quantity applied	Mortality at 15–20 cm.		30–35 cm.		50–55 cm.	
		dead	alive	dead	alive	dead	alive
2.ix.38 ...	150 cc.	10	3	9	6	12	2
21.xi.38 ...	150 cc.	23	1	12	21	2	20
21.x.38 ...	120 cc.	21	0	12	1	0	12
21.xi.38 ...	120 cc.	3	6	9	25	2	42
24.viii.38 ...	100 cc.	19	8	16	12	8	12
21.xi.38 ...	100 cc.	3	13	6	27	2	33
8.ix.38 ...	60 cc.	1	10	4	15	4	17

A study of Table I shows that the results are not uniform, especially when smaller dosages were used, and when the larvae were buried at the farther distances from the point of application. This is due to the fact that other factors such as the consistency of the soil and the depth to which the larvae had penetrated the wood, are involved. Nevertheless certain facts do emerge :—

(*a*) 60–100 cc., when applied in the centre, may yield a good kill of larvae within a radius of 20 cm., but beyond this area, the mortality is not always satisfactory.

(*b*) 120 cc., when applied in the centre, yields a satisfactory percentage of mortality up to a radius of 35 cm.; beyond it, only 20 per cent. of the larvae died.

(*c*) 150 cc., when applied entirely in the centre, yielded a satisfactory mortality up to a radius of 35 cm.; at a radius of 50 cm., only about 50 per cent. of the larvae died.

(*d*) When application was made in four parts, the mortality not only did not increase, but the general percentage in the entire area decreased. Thus when 150 cc. was applied in the centre, there was a total mortality of 88 per cent., while when this amount was applied in four parts, only 54 per cent. died. Similarly 120 cc., when applied entirely in the centre, caused a mortality of 80 per cent., whereas only 45 per cent. died when divided into four parts.

(*e*) Regardless of whether application was entirely in the centre, or divided into four parts, the mortality of the larvae in the inner pieces of wood was always the largest.

Pure Substance versus Emulsion.

It has been recommended that for the control of peach borer, ethylene dichloride should be used in the form of an emulsion diluted in water.

TABLE II.

A.

Ethylene dichloride applied in pure form in the centre of area.

Quantity	Mortality at 20 cm.		35 cm.		50 cm.	
	dead	alive	dead	alive	dead	alive
150 cc.	17	0	18	1	16	1
100 cc.	18	0	—	—	0	48

B.

Ethylene dichloride applied as a 10 per cent. emulsion poured over the surface.

Quantity	Mortality at 20 cm.		35 cm.		50 cm.	
	dead	alive	dead	alive	dead	alive
150 cc.	8	0	13	12	2	9
100 cc.	18	0	—	—	2	35
100 cc. 30°C.	23	2	12	10	12	8
100 cc. 65°C.	13	0	14	13	12	10

A few experiments were carried out to determine whether it was more efficient when used in the form of an emulsion diluted in water, or when used in pure form. 150 cc. pure ethylene dichloride was poured in the centre of an area one metre in diameter, where *Capnodis* larvae were buried, and 150 cc. was emulsified in 1·5 litres of water and poured over the surface of a similar sized area. The experiment was repeated, using 100 cc. of pure substance and 100 cc. diluted in one litre of water. The results of these tests are given in Table II.

Several more experiments were carried out, the results of which indicated that the emulsion is not superior to pure ethylene dichloride, when used in proportions containing equal amounts of the substance. The application in diluted form gave entirely unsatisfactory results.

It was suggested that perhaps a warm emulsion, when applied to the ground, might yield better results. An experiment was therefore carried out in which a cold emulsion at 30°C. and a warm emulsion at 65°C. were applied separately in the same dilutions. No difference in mortality resulted as will be seen from Table II, last two lines.

Experiments in the Grove.

For the sake of comparison, some of the results of the experiments carried out in the grove by Dr. Shweig, are presented in Table III. The method of application was always in the form of an emulsion. The dilute emulsion in proportions specified in the table were either poured into a circular groove around the tree, or poured over a burlap rag which was buried around the tree about 10 cm. away from the trunk. In the experiment of August 1939, 60 trees were tested but 43 only were infested. In this instance the emulsion was poured over a burlap rag. In the next experiment in December 1939, 18 infested trees were used in 13 of which the dilute emulsion was poured into a groove around the tree, whilst in the remainder, the dilute emulsion was poured over a burlap rag as in the experiment of August 1939.

TABLE III.

Temp. of emulsion	Amount of emulsion in litres	Per cent. of ethylene	Approx. amount of ethylene	No. of trees	No. of dead larvae	No. of living larvae
30°	1·500	10	140 cc.	8	29	9
50°	1·500	10	140 cc.	4	5	2
30°	1·500	15	210 cc.	10	37	11
50°	1·500	15	210 cc.	8	25	1
30°	1·500	20	280 cc.	7	15	7
50°	1·500	20	280 cc.	6	12	6
	2·100	20	380 cc.	13	59	25
	2·100	20	380 cc.	5	36	7

The following points emerge from a study of Table III :—

(*a*) Approximately three-quarters of the total number of the larvae treated were killed.

(*b*) No marked difference in the mortality was noticed when the dosage was increased from 140 to 380 cc. per tree.

(c) Temperature of the emulsion had no effect on toxicity.

(d) There was virtually no difference in results between applications made directly on the soil, or over a burlap rag.

Furthermore, it should be mentioned that a much smaller percentage of the pupae died. Of a total of 15 pupae recovered, only seven were dead; nor were the adults killed by the gas.

Effect upon Trees.

Heavy applications of ethylene dichloride were given to healthy apricots and almonds in order to determine the effect on the tree.

The trees selected were planted in heavy soil, typical of the mountains of Palestine, in the neighbourhood of Mt. Carmel. Three apricot trees, grafted on a local apricot variety, eight years old, and three almond trees, grafted on bitter almond three years old, were chosen and the first application took place in August 1938.

One apricot tree was given 100 cc. of ethylene dichloride, applied in four holes around the tree about 15 cm. away from the trunk, another was given 100 cc., poured in a hole near the trunk, whilst a third tree was given 150 cc., applied in three holes 15 cm. distant from the trunk.

Each of the almond trees was given 50 cc. of the pure substance in one hole near the trunk.

The trees were examined two months later, and no ill effects were observed.

Injury to trees, due to application of ethylene dichloride, was reported by some farmers, and is mentioned in the literature (Snapp, 1944). The reason for this may have been that it was applied in the form of an emulsion, in which case the liquid may have come in direct contact with the roots, or it may have been due to the heavy doses, almost 400 cc., which were applied to each tree. Furthermore, there may be a cumulative injury which was not observed by the writer.

Since ethylene dichloride proved to be unsatisfactory inasmuch as large doses were required to bring about an adequate mortality, other substances were sought and compounds of bromide were tried. Preliminary experiments indicated that ethylene bromide compounds were stronger than chlorides and much smaller doses were necessary.

Ethylene Bromhydrin.

Three bundles of infested almond wood sections were buried in a row in the ground at a distance of 20 cm. from each other and 10 cc. of ethylene bromhydrin was poured into a hole in the middle of the row. After the lapse of four days, the sections were removed and examined.

In the centre bundle all the larvae were dead while, in the bundles at the extreme end, one-third of the larvae were alive.

In another experiment, the bromhydrin was mixed with water and poured over three bundles of wood arranged as in the foregoing experiment. In this instance, about one-third of the entire number of larvae were alive.

Ethylene Dibromide.

In preliminary experiments carried out in 1937, it was found that 5 cc. of ethylene dibromide was sufficient to kill all the larvae buried in the ground at a depth of 30 cm., when applied directly over it and that even at a distance of 10–20 cm. it was quite effective in bringing about a complete mortality. In 1944, further experiments were carried out in order to ascertain :—

(a) The minimum amount required to kill the larvae in a tree;

(*b*) How far the fumes penetrate into the ground and remain effective ;

(*c*) Which is the best method of application ;

(*d*) What is the sublethal dose applicable to the tree.

It was necessary to apply the latter experiments separately on healthy trees. The other experiments were carried out in a manner similar to those with ethylene chloride except that the bundles at 20 cm. were omitted as it was apparent that complete mortality would take place in the larvae inhabiting them.

In the first experiment it became evident that, even when a very large dose of 30 cc. is applied, mortality at 50 cm. is not always complete. Such a large dose may prove to be detrimental to the tree and therefore the application of heavier doses to kill larvae at great distances was abandoned, and the experiments were confined to an attempt to kill at a distance from 30–35 cm. only. Hence, the bundles buried at 50 cm. were also omitted from the later experiments and the liquid was applied in the centre only. In an experiment in which 120 cc. was divided into four parts, it was evident that a better kill was obtained by application entirely in the centre as only ten out of 64 larvae were killed.

The results of the experiments with ethylene dibromide, carried out in 1944, are detailed in Table IV :—

TABLE IV.

Fumigation Experiments with Ethylene Dibromide against Capnodis *Larvae.*

Date	Amount of substance	Condition of soil	Mortality at 30–35 cm. dead	Mortality at 30–35 cm. alive	Mortality at 50–55 cm. dead	Mortality at 50–55 cm. alive
4.viii.44	30 cc.	Slightly moist	92	0	25	3
4.viii.44	25 cc.	„ „	—	—	60	0
4.ix.44	20 cc.	Dry	—	—	17	1
4.xii.44	10 cc.	„	20	0		
4.xii.44	10 cc.	Moist	20	0		
4.xii.44	10 cc.	Surface moist	24	0		
22.viii.44	6 cc.	Moist	16	0		
16.ix.44	4 cc.	Dry	13	8		
24.ix.44	4 cc.	„	0	23		
	3 cc.	„	5	20		
3.ix.44	4 cc.	Moist	15	0		
	4 cc.	Surface moist	12	0		
29.ix.44	4 cc.	„ „	11	5		
6.x.44	4 cc.	„ „	15	2		
	3 cc.	„ „	34	0		

Table IV brings out the following points :—

(*a*) Total mortality of all larvae within an area of approximately one square metre may be brought about by the application of 25–30 cc. of ethylene dibromide in a hole in the centre, but under certain circumstances a small percentage may escape. The three live larvae (line 1) were all buried in one piece of wood, which had a thick and tough bark, and the burrows of the larvae were deeply imbedded in the middle of the wooden cylinder, thus escaping the poisonous fumes. As in the case of ethylene dichloride, the mortality was far less when the same amount was applied in four parts.

(*b*) At a distance of 35 cm., 6 cc. gave a 100 per cent. mortality and at a dosage of 3–4 cc. a satisfactory kill of larvae may be obtained, provided that the substance is well applied and the soil is properly prepared.

(*c*) In dry soil, the mortality when small dosages are applied is far less than when the soil is moist or moistened on the surface.

Application in the Field.

(*a*) *Soil Conditions.*

It was observed that, whether ethylene dibromide or ethylene dichloride is used, the fumes penetrate through compact layers of soil, but that penetration is far easier and a better mortality is obtained when the soil is less compact. It is therefore preferable to apply the gas after the soil has been cultivated.

On several occasions it was noticed that the mortality in moist soil is far greater than in dry soil; experiments have shown (see Tables III and IV), that it is sufficient to sprinkle water on the upper surface of the soil to ensure a higher rate of mortality. In the experiments with ethylene dibromide, where from 3–4 cc. were used, at a distance of 35 cm., 18 larvae only out of 69 died when the soil was dry, whereas 87 out of 94 died when the soil was slightly wet or its surface only slightly sprinkled with water. It may be that, when the soil is heated and consequently very dry, air currents from the lower layers in the soil, which are directed upwards, prevent penetration of the fumes. By moistening the upper surface and thereby cooling it, the air currents in the soil are directed downwards and thus help the penetration of the fumes. Furthermore, by moistening the upper surface, the spaces between the soil particles are decreased, being filled with water, and the outlet for the fumes from the soil is thus considerably reduced. The difference in mortality is so much greater when the soil is moistened than when it is dry, that it is advisable to sprinkle a little water around the trees before treatment.

(*b*) *Emulsion or pure Substance.*

An emulsion of ethylene dichloride was recommended to give dilution and enable equal distribution around the tree to be made. On the assumption that the gases penetrate directly downwards, it was considered necessary to apply it around the tree wherever the pest might be present. Experiments by the present writer show that this is entirely unnecessary. The pure material, when applied in one spot, in the ground, will also penetrate sidewards through an area of about one metre in diameter, and bring about mortality of the larvae in all the roots situated therein. Naturally the closer the larvae are to the point of application, the higher the mortality. A satisfactory mortality with a small dose was attained at a distance of from 30–35 cm.

(*c*) *The Dosage.*

A satisfactory mortality with ethylene dichloride within an area of 70 cm. in diameter was obtained with a dosage of 120 cc., but if the soil surface is moistened no doubt less material would be necessary. Similarly good results were obtained with 4 cc. of ethylene dibromide.

The following practical recommendations may be made. For young trees, one to three years old, 4 cc. of ethylene dibromide, or 60 cc. of ethylene dichloride, applied in a hole near the trunk of the tree. For older trees, of the age of seven to eight years, twice the amount is advised, 4 cc. of ethylene dibromide on one side and 4 cc. on the opposite side, at a distance of 25 cm. from the trunk. In this way an area of over a metre in diameter will be fumigated effectively. For older trees, 150 cc. ethylene dichloride and three times the amount of dibromide is recommended —namely, 4 cc. of ethylene dibromide at each of the angles of an equilateral triangle, each hole being about 30 cm. distant from the trunk. This will ensure that an area of about 1½ metres in diameter is effectively fumigated.

Effects upon Trees.

Ethylene dibromide is a very poisonous gas, and when used in larger quantities, or when in contact with the plant tissue, causes injury. The gas was tested on healthy trees in large doses as follows :—

(*a*) Forty cc. of the pure liquid were poured around the trunk of each of two old almond trees. It was applied in four parts, 10 cc. in each of four holes in the ground, about 30 cm. distant from the trunk. The treatment was carried out early in September 1944 and by the middle of October no ill-effects were observed.

(*b*) Fifteen cc. of ethylene dibromide in 3 parts, 5 cc. in each of three holes in the ground, about 30 cm. away from the trunk was applied to a young almond tree 6 years old.

(*c*) Three plum trees about ten years old were given 20 cc. each, applied in two doses, 10 cc. in each of two holes 30 cm. away from the trunk.

A month later, early in October, no ill-effects were observed on these four trees (*b* and *c*). Towards the end of October the treated plum trees showed an earlier discoloration of the leaves, but otherwise there were no ill-effects. In the spring of 1946 all four trees were quite normal. The quantities of fumigant used, it will be noted, were about twice those required to kill the larvae of *Capnodis*. The writer recommended to farmers the application of 12 cc. for older trees, and 4 cc. for young trees. No reports of injury have been received.

Contact Insecticides for Larvae.

As a possible solution to the problem of *Capnodis*, the sprinkling around the trees was suggested of some dry chemical substance which in itself would not be harmful to the soil or to the roots, but would kill the neonate creeping larvae searching for roots. Although this did not appear to be a very promising line to follow, a few experiments were carried out to determine what dry substances, harmless to the tree and soil, will kill the larvae by contact.

A cotton plug was forced into a test tube, close to, but not touching, the bottom. A layer of sand, about 15 cm. deep, was poured over this and, in turn, covered by a layer of about 15 cm. of sand mixed with the chemical to be tested, whilst over this mixture, a layer of pure, moist sand was introduced. The chemical was mixed at a ratio of 1 to 10 parts of sand. Fifteen larvae were placed on the top of the upper layer of sand into which they began to burrow. Thirty hours later, the tubes were carefully emptied and the larvae sought. Five tubes were so arranged, using ferrous sulphate, sulphur, calcium copper sulphate and calcium hydroxide respectively in four of the tubes whilst in the fifth pure sand was used as a control.

The results of this experiment, will be found in Table V.

TABLE V.

	On the surface	In the upper sand layer	In chemical and sand layer	Below the chemical layer	Number larvae lost	Condition of larvae
Ferrous sulphate ...	1	—	—	13	1	All alive
Sulphur	—	3	4	6	2	2 in chemical dead; 2 alive
Calcium copper sulphate	14	—	—	1	—	All quite active
Calcium hydroxide ...	13	2	—	—	—	All alive but faint
Control (sand)	13 found in the sand at various depths				2	All alive

Most of the larvae passed through the ferrous sulphate without being injured Sulphur probably killed a few larvae, but at least eight passed through without injury. The other two compounds seemed to repel the larvae. It is quite possible that they made attempts to penetrate deeper, but upon coming in contact with the chemical layer were driven back.

Spraying against Adults.

In the literature barium fluosilicate and other stomach poisons are recommended against *Capnodis* (Pussard, 1934).

In Palestine the practice of spraying the trees with a 0·7 per cent. suspension of lead arsenate was introduced a few years ago by Dr. Shweig. It was noticed by him that a number of adult beetles were found dead under the trees after the application of such a spray for the control of the Mediterranean Fruit Fly (*Ceratitis capitata*), thereby reducing the beetle population considerably. Experiments were, therefore, carried out to determine how long it takes for the beetles to die after feeding on various poisons, and to find a substitute for lead arsenate of which repeated applications are undesirable.

Six substances were tested, 25 beetles being used for each test. The beetles—*Capnodis carbonaria*—were collected in an almond grove during the period of August–October, and divided into batches of three lots of 8 or 9.

Blood albumin was added as a spreader to the poison suspension to be tested. While the suspension was stirred, the twigs which were to serve as food were dipped into it, dried and given to the captive beetles. In some tests the poison was given with each meal until the end of the experiment; in other tests the poison was given only once, and the subsequent meals, which were given every two days were free from the poison. In some tests the poison was applied as a dust on the twigs.

Details of the experiments were as follows :—

(1) Lead arsenate 1 per cent. ... Spray applied only once.
(2) „ „ 1 „ „ ... „ with every feeding.
(3) Barium fluosilicate 1 per cent. ... „ applied only once.
(4) „ „ 1 „ „ ... „ „ with every feeding.
(5) „ „ 2 „ „ ... „ „ only once.
(6) Cryolite 1 „ „ ... „ „ with every feeding.
(7) „ 2 „ „ ... „ „ only once.
(8) Phosphorite 3 „ „ ... „ „ with every feeding.
(9) „ pure dust ... ... „ „ „ „ „
(10) Penta-erythryl-bromide ... ... Pure dust applied with every feeding.
(11) DDT 0·2 per cent. ... ... Spray „ „ „ „
(12) „ 1 „ „ ... ... Dust „ „ „ „

The dibromide compound did not act at all; the beetles survived over 30 days. Phosphorite, a local phosphorum compound, which contains 5 per cent. fluoride, was also not effective. Of the 10 beetles under test, one died before the end of 10 days, four died during the second ten days' period, while the other five lived longer than 30 days which is very much like the control.

The beetles did not feed sufficiently on the twigs treated with 0·2 per cent. DDT, but although they did not die they remained inactive. Dust containing 1 per cent. DDT killed 70 per cent. of the beetles within 6 days. Further experiments with larger doses are required both in the laboratory and in the field before a definite conclusion can be reached.

Lead arsenate gave the quickest results. At a concentration of 1 per cent., when the poison was given with each meal, 80 per cent. of the beetles died within three days whilst the others succumbed two or three days later. When the poison was given with one meal only, 50 per cent. died after five days, a few more died within the following few days, but some lived for over two or three weeks not apparently having ingested sufficient quantities of lead arsenate.

Barium fluosilicate at a concentration of 2 per cent. gave fair results. When applied with each meal 40 per cent. died after three days, an additional 40 per cent. within the first week and the remainder within the following week. When given only once, the subsequent meal being free of poison, about 50 per cent. died before the end of the 8 days' period, the remainder surviving a second and a third week and some living even longer than three weeks.

A 2 per cent. solution of cryolite gave results identical with, if not better than, those with barium fluosilicate and when 1 per cent. was applied with each meal about 30 per cent. of the beetles survived for two and three weeks. Of all the substances tested, this is the least harmful to the trees and as toxic to *Capnodis* as others and should be adopted in the groves.

Time to Spray.

When determining the time to apply the spray it should be remembered that oviposition does not take place below a temperature of 26°C., and that the beetles become active only at the end of March. At that time over-wintering beetles emerge from their hiding places in the ground, and several weeks later new beetles begin to emerge, a process which continues throughout the early summer. It should be borne in mind that the preoviposition period with *Capnodis* lasts at least five weeks. This being the case it is advisable to give the first application during the month of April. The hot dry days will bring up from the ground whatever overwintering adult beetles there may be, and drive them to the trees to feed when they will be killed. May and June will bring a host of newly emerged beetles from the ground. The possibilities are that several of these will find new non-poisoned food and escape death. Such beetles may live five weeks without causing any serious harm and a second application late in May or early in June is recommended to deal with them. This application is apt to diminish the emergence of the beetles during May and June considerably for at this time there is no new growth, and all the available food has been sprayed. Emergence in July and August is very slight, and there is very little need for a third spraying. Should observation indicate, however, an increased population of the beetles, an application during July will reduce them. A subsequent spraying is not necessary since new beetles emerging in August will not lay that summer.

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GENERAL OBSERVATIONS ON MOSQUITOS IN RELATION TO YELLOW FEVER IN THE ANGLO-EGYPTIAN SUDAN.

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Introduction.

Most of the southern half of the Sudan is a yellow fever area in the sense that people immune to the disease have been found in many parts of it. The chance of yellow fever spreading to areas hitherto free is liable to be increased by outbreaks such as the Nuba Mountains epidemic of 1940 which, in the words of the East African Medical Journal (Anon., 1941), far exceeded " in magnitude any that have ever been recorded even on the West Coast, at least within the present generation." Several of the towns in the Sudan lie on important air, rail and water routes leading to countries free of yellow fever to the north and east (Whitfield, 1939, has discussed air routes in this connection). Twelve of the 140 kinds of mosquitos which are found in the Sudan are known to be capable of transmitting yellow fever virus by bite and several others must be suspected (Table I). Kirk (1943) has discussed the epidemiology and control of yellow fever in the Sudan and summarised previous work.

TABLE I.

Mosquitos occurring in the Sudan whose relation to yellow fever has been investigated experimentally, with references to authorities.

(1). Mosquitos known to be able to transmit virus by bite	
Taeniorhynchus (*Mansonioides*) *africanus*, Theo.[3] ...	Philip (1930)
Aëdes (*Stegomyia*) *aegypti*, L.	Many authors
,, ,, ,, var. *queenslandensis*, Theo. ...	Lewis, Hughes & Mahaffy (1942)
,, ,, *simpsoni* var. *lilii*, Theo.[1]	Philip (1929)
,, ,, *metallicus*, Edw.	Lewis, Hughes & Mahaffy (1942)
,, ,, *africanus*, Theo.	Philip (1929)
,, ,, *luteocephalus*, Newst.	Bauer (1928)
,, ,, *vittatus*, Bigot	Philip (1929)
,, (*Aëdimorphus*) *stokesi*, Ev.	Bauer (1928)
,, (*Diceromyia*) *taylori*, Edw.	Lewis, Hughes & Mahaffy (1942)
Eretmapodites chrysogaster, Graham	Bauer (1928)
Culex (*C.*) *fatigans*, Wied.[2]	Davis (1933)
(2). Mosquitos able to retain the virus throughout life but apparently unable to transmit it by bite	
Taeniorhynchus (*Mansonioides*) *uniformis*, Theo.[3] ...	Kerr (1932)
Aëdes (*Banksinella*) *lineatopennis*, Ludl.[4]	Kerr (1933)
(3). Mosquitos unable to retain the virus more than a short time.	
Anopheles (*Myzomyia*) *gambiae*, Giles	Philip (1930)
Aëdes (*Stegomyia*) *apicoargenteus*, Theo.	Bauer (1928)

[1]Found infected in nature by Mahaffy and others (1942).
[2]Not an efficient vector.
[3]Edwards (1941) considered experimental result with *T. africanus* and *T. uniformis* somewhat conflicting in view of their structural similarity. More work seems desirable.
[4]No particulars or reference to experiments.

Anti-mosquito measures to prevent the spread of yellow fever are essential, and have been in force for many years. Since much remains to be learnt about the epidemiology of yellow fever, and since new outbreaks may occur in the future, changes in the control measures may become necessary. It seems desirable, therefore, to record some information about the bionomics and distribution of Sudan mosquitos. The Anophelines are only briefly considered because they appear unlikely to transmit yellow fever. None has yet been shown to be able to do so. Philip (1930) found that "experiments with *Anopheles gambiae* failed to produce infection in test animals through bite or by injection of the ground-up insects after a period equivalent to that required by *A.* [*Aëdes*] *aegypti* to become infective by bite" and considered that the species was not concerned with transmission in West Africa. The other principal house-haunting Anopheline, *Anopheles funestus*, seems unlikely to be a potential vector because it is abundant in many areas where no epidemic has been observed although the disease appears to be endemic.

Edwards (1941) stated that "it would seem that most of the common biting mosquitos of West Africa are to be regarded as potentially dangerous." Apart from the few Culicines in the Sudan that bite man and frequent houses, there are many common species, which can be divided into two classes: (1) those that bite man readily and do not frequent houses, and (2) those that seldom or never bite man. The first class requires study because it is possible that rural epidemics of yellow fever may occur in which the virus will be transmitted by wild mosquitos. There seems good reason to believe (Lewis, 1943) that one of the principal vectors in the Nuba Mountains epidemic was a species (*Aëdes taylori*) described for the first time only four years before, that had not previously been known to bite man, and had been recorded from only two places in Africa, each over 1,000 miles from the Nuba Mountains. The species which do not bite man are of indirect importance in that knowledge of their distribution is useful in planning "species sanitation" of important species and avoiding the waste of money on controlling common non-man biters such as *Culex univittatus*. Many common Culicines, man-biters or not, may be of interest in relation to the persistence of virus in areas where human cases are rare and in areas to which the virus may spread, possibly into some animal reservoir. Kirk (1943, p. 147), commenting on the reasons for the distribution of yellow fever in certain areas, writes "further elucidation of the factors concerned is more than a matter of academic interest. At present it is uncertain whether conditions favouring endemicity exist in other parts of the world [other than certain parts of South America and Africa], which have been free from yellow fever so far, but into which infection may spread; yet the results of any proposed control measures might be profoundly affected by this consideration."

Most of the present paper, therefore, is devoted to a general survey of various facts about the common Culicines of the Sudan. It contains information additional to that recorded by Lewis (1943) on bionomics in relation to yellow fever and Lewis (1945) on distribution and taxonomy.

Notes on the Bionomics of some Common Sudan Mosquitos.

Table II summarises the known facts regarding the man-biting habits of Sudan mosquitos. They are based on personal observations, particularly by evening outdoor catches, in areas where the prevalence of each species was known. It seems probable that a single record of a common species biting man (e.g. *C. univittatus*) does not necessarily show that it should be regarded as a man-biting species. It would not be surprising if occasional specimens of man-ignoring species bit man in view of the frequency with which plant-sucking Jassid bugs pierce human skin. Several records, by other workers and the writer, of mosquitos taken on man are ignored because biting was not actually observed. Most of the observations were made in the northern and central parts of the country, and some were made in the

TABLE II.

A summary of observations on the biting habits of mosquitos in relation to man in the Sudan (*Megarhinus* and *Harpagomyia* omitted from list).

(1). Mosquitos that bite man readily

Anopheles
- (*Anopheles*)
  - *coustani*, Grp.
  - ,, var. *ziemanni*
- (*Myzomyia*)
  - *funestus*, Giles
  - *rivulorum*, Leeson[1,3]
  - *theileri* var. *septentrionalis*, Ev.[1,2]
  - *wellcomei*, Theo.
  - *gambiae*, Giles
  - *rufipes*, Gough
  - *pharoensis*, Theo.
  - *squamosus*, Theo.

Taeniorhynchus
- (*Coquillettidia*)
  - *cristatus*, Theo.
- (*Mansonioides*)
  - *africanus*, Theo.
  - *uniformis*, Theo.

Aëdes
- (*Ochlerotatus*)
  - *caspius*, Pall.
- (*Stegomyia*)
  - *aegypti*, L.
  - ,, var. *queenslandensis*, Theo.
  - *simpsoni* var. *lilii*, Theo.
  - *metallicus*, Edw.
  - *luteocephalus*, Newst.
  - *unilineatus*, Theo.

Aëdes
- (*Stegomyia*)
  - *vittatus*, Bigot
- (*Aëdimorphus*)
  - *argenteopunctatus*, Theo.
  - *leesoni* subsp. *verna*, Lewis
  - *dentatus*, Theo.
  - *cumminsi*, Theo.
  - *centropunctatus*, Theo.
  - *hirsutus*, Theo.
  - *ochraceus*, Theo.
- (*Banksinella*)
  - *lineatopennis*, Ludl.
  - *circumluteolus*, Theo.
  - *albothorax*, Theo.
- (*Diceromyia*)
  - *furcifer*, Edw.
  - *taylori*, Edw.

Eretmapodites
- *chrysogaster*, Graham[4]

Culex
- (*Culex*)
  - *poicilipes*, Theo.
  - *univittatus* var. *neavei*, Theo.
  - *pipiens* subsp. *molestus*, Forsk.
  - *fatigans*, Wied.[5]
  - *antennatus*, Beck.

(2). Mosquitos common in some areas which are seldom or never found biting man.

Anopheles
- (*Myzomyia*)
  - *pretoriensis*, Theo.

Aëdomyia
- *africana*, N.-L.

Theobaldia
- (*Allotheobaldia*)
  - *longiareolata*, Macq.[8]

Ficalbia
- (*Mimomyia*)
  - *splendens*, Theo.
  - *lacustris*, Edw.
  - *mimomyiaformis*, Newst.
- (*Etorleptiomyia*)
  - *mediolineata*, Theo.
- (*Ficalbia*)
  - *uniformis*, Theo.

Taeniorhynchus
- (*Coquillettidia*)
  - *chrysosoma*, Edw.

Culex
- (*Lutzia*)
  - *tigripes*, G. & P.
- (*Culiciomyia*)
  - *nebulosus*, Theo.
  - *cinereus*, Theo.
- (*Culex*)
  - *ethiopicus*, Edw.
  - *duttoni*, Theo.
  - *univittatus*, Theo.[7]
  - *sinaiticus*, Kirkp.
  - *laticinctus*, Edw.
  - *decens*, Theo.

(3). Common species on which more observations are required.

Anopheles
- (*Myzomyia*)
  - *nili*, Theo.[6]
  - *rupicolus*, Lewis
  - *rufipes* var. *ingrami*, Edw.[6]

Uranotaenia
- *balfouri*, Theo.

Taeniorhynchus
- (*Coquillettidia*)
  - *metallicus*, Theo.

Aëdes
- (*Mucidus*)
  - *scatophagoides*, Theo.[1]
- (*Aëdimorphus*)
  - *arabiensis*, Patton[6]
  - *fowleri*, d'Emm.

Culex
- (*Culex*)
  - *perfuscus*, Edw.[1]

(4). In addition to the above there are 75 forms of mosquitos that have not been found biting man in the Sudan but were too uncommon for thorough observations to be made.

[1]Only once seen to bite man.
[2]Bit near swamp.
[3]Bit out-doors.
[4]Observation by Mr. C. B. Symes.
[5]Observation made in Eritrea.
[6]Caught on person but biting not observed.
[7]Hardly ever seen biting, the other spp. of *Culex* never.

south during the dry season. Most of the man-biting species are sufficiently abundant in some areas to be of practical importance; information on the distribution and details of some catches of these are given in the section below on areas.

A few species have been collected while biting animals, as shown in the following list :—

	Cow	Donkey	Sheep	Horse
Anopheles coustani var. *ziemanni*	×	×		
„ *funestus*	×			
„ *wellcomei*	×			
„ *rufipes*	×		×	
„ *pharoensis*	×	×		
Taeniorhynchus africanus	×	×		
„ *uniformis*	×	×		
Aëdes vittatus				×
Culex poicilipes	×		×	
„ *antennatus*	×		×	

Little reference is made to breeding places because the subject has been so fully dealt with by Hopkins (1936). Larvae of many species have been found in domestic water vessels but most of them were probably brought from outdoor breeding places.

The carriage of mosquitos in steamers and trains is of considerable interest. Mosquitos probably behave in relation to them as they do in relation to houses. The house-haunting species tend to remain in them during the day. The "wild" man-biting species apparently act similarly at night when they seek an immediate resting place after they are gorged with their evening feed, and some are trapped by mosquito screening in the morning. Notes on species found are given below in the section on areas. Past records of species found in aircraft are of little practical interest in view of the efficient spraying methods now used. It may be noted, however, that Whitfield (1939) obtained 16 species in aircraft landing at Khartoum. A large proportion came from Asmara where the house-haunting *Culex fatigans* was common (Lewis, 1943a).

Anopheles.

Anopheles coustani var. *ziemanni* is common whilst *A. pharoensis* occurs in immense numbers in certain areas. Both species bite man readily near their breeding places, particularly from about 25 minutes to an hour after sunset. *A. wellcomei* behaves similarly but is less abundant. *A. squamosus* is seldom seen biting; in the central Sudan it breeds chiefly in the rainy season. *A. rufipes* is rarely found biting out of doors in the evening; in some places it is common in houses by day and occasionally even outnumbers *A. gambiae*.

Uranotaenia balfouri.

Balfour (1904) reported that species of *Uranotaenia* were vicious on the River Pibor, and Theobald (1904) stated that *U. balfouri* was the cause of the annoyance. Edwards (1941) stated that none of the African species of this genus had been observed to suck human blood, and the writer has spent considerable periods in areas where *U. balfouri* was abundant without seeing any biting. Kerr (1933) found species of *Uranotaenia* on man, and Davis & Philip (1931) identified chicken blood in *U. annulata*. Further observations on *U. balfouri* are desirable.

Taeniorhynchus africanus and T. uniformis.

These two species usually occur together, often in large numbers, *T. uniformis* usually being the more numerous. It was outnumbered by *T. africanus*, however, in collections made at Malakal (some of catches), El Amira, El Liri, Lul and Melut (Map 3). At El Liri all larvae examined were *T. africanus*.

Hopkins (1936) has pointed out that, although larvae of the two species usually occur among *Pistia*, they can live among other amphibious plants. Both have been found breeding near Malakal in grassy swamps.

Habits of Adults.

As in Kenya (Haddow, 1942), these species do not normally rest in houses by day. Most of the comparatively small number obtained in steamers and houses by day were *T. africanus*. On one occasion, when a steamer grounded for a short time in the Sadd area, seven *T. africanus* and 41 *T. uniformis* were caught in a few minutes. On the following morning 20 *T. africanus* and ten *T. uniformis* were found in a part of the crew's quarters examined.

In view of its habits in the Sudan it is interesting to note West African records of *T. africanus* as a house-haunting species. Beeuwkes and others (1933) found it in houses in Kano, and Philip (1930) in Lagos, but in the former the number per house was small and in both cases there were breeding places nearby. Kerr (1933) found that at Lagos the adults were most abundant near swamps and equally abundant inside and outside houses. These accounts do not appear to show that the habits of *T. africanus* in the Sudan differ from those of the West African representative.

Females of both *T. africanus* and *T. uniformis* bite readily near swamps in the evening and to a lesser extent by day, and the latter has been found biting in large numbers near a swamp after sunrise. From the work of Davis & Philip (1931) it appears that *T. africanus* definitely prefers to bite man rather than chickens, if it bites the latter at all. Mr. H. Bell, formerly of the Egyptian Irrigation Department, has observed mosquitos (almost certainly *T. uniformis* or both species) biting at Shambe on several occasions by day. He informed the writer that when he walked near the swamps he was not bitten but when he rode on his grey horse he was bitten by a few and the horse by many mosquitos.

Females of *T. uniformis* have been observed on, and apparently sucking, the calyces of *Plumieria acutifolia* (frangipani).

Relation to Yellow Fever.

The relation of *T. africanus* to yellow fever is of great interest in view of the wide distribution of this mosquito and the huge numbers in which it occurs in some areas. Although Philip (1930) found that *T. africanus* could transmit the virus by biting, he considered that it retained the infection less readily than did *Aëdes aegypti*. Edwards (1941) considered that Kerr's (1932) negative results with the very similar *T. uniformis* somewhat discounted Philip's results. Further experiments are desirable.

Experience with *T. africanus* in the field provides no definite evidence of its rôle as a vector. Beeuwkes and others (1933), finding some in houses in Kano, thought it might play some part in transmission. The situation on the Upper Nile is interesting. The work of Findlay & others (1941) indicates that yellow fever has occurred at Malakal and Kaka and possibly at Tonga. All these places lie on a stretch of river along which, from July to December, swamps exist in which *T. africanus* breeds in large numbers. During the rest of the year some aquatic vegetation remains in a few places. It is very unlikely that *Aëdes aegypti* or other species of *Stegomyia* (although *A. simpsoni* var. *lilii*, *A. metallicus*, *A. luteocephalus*, *A. unilineatus* and *A. vittatus* have been found) can have played a part. Owing to the importance of

the aerodrome, they have been under control at Malakal for many years, and no species of *Stegomyia* has been found at Kaka or Tonga or in the surrounding country. The people, living by the river, have no incentive to store water and there are few trees near most villages. Soper (1938) expressed surprise at the results of the yellow fever surveys in view of the scarcity or absence of *Aëdes aegypti*. It seems probable that *T. africanus* or other species, or all the common Culicines, have transmitted yellow fever in the area. One might ask why, if an efficient vector was present, a noticeable epidemic did not occur, but such an epidemic is unlikely because the people live at some distance from the swamps and many make smoke fires to keep off mosquitos, and also because none of the Culicines is a house-haunting species. A limited degree of transmission, however, appears to be possible. There are several landing stages at which a number of people gather and are bitten by *T. africanus* from the nearby vegetation. In Malakal itself, where many *T. africanus* bite at night, there is possible day-time shelter for the mosquitos in the shape of trees, hedges, gardens and irrigation culverts, and many have been found in a cattle stable by day. Under these circumstances it seems likely that females of *T. africanus* might become infected and remain near human beings long enough to become infective and bite people.

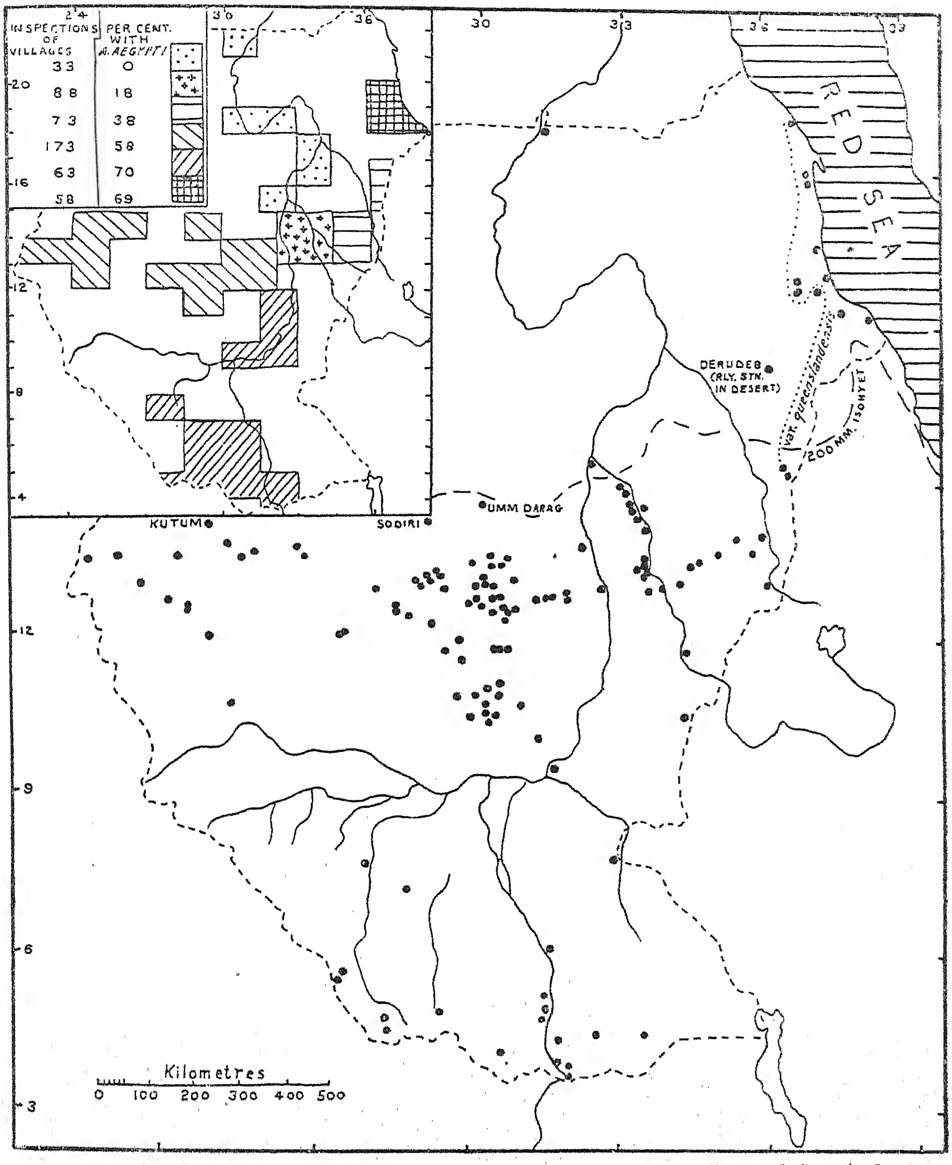
Although the situation at Malakal affords no evidence of the rôle of *T. africanus*, it is quite in accordance with the supposition that this species can act as a vector in small limited epidemics.

Aëdes aegypti and var. queenslandensis.

Distribution.

This has been studied by means of specimens received for identification from members of the Public Health Section of the Sudan Medical Service and by surveys made by the writer. All towns and many villages situated on lines of communication have been examined. Map 1 shows where *A. aegypti* has been found and the percentage of villages found infested by the Headquarters Aëdes Control Unit (referred to below) in certain areas indicated by groups of map sections. The southern area was visited mainly in the rains. The map does not represent the present position but summarises past records. Except near the coast few places had a house index (number of houses containing larvae expressed as a percentage of the number of houses examined) of more than 50 per cent. In preparing the map it was found that plotting the house index showed little difference between areas, but that plotting the village index showed great differences. This was probably because the areas were visited at different times of year and the house index varied with the seasons. In the south the areas without records are either uninhabited or are remote areas where surveys have not been made. In the north the desert lies on each side of the river, and along the Nile north of Khartoum is the only considerable inhabited area where *A. aegypti* has scarcely ever been found despite careful searches. It was once found at Wadi Halfa, probably as the result of a chance introduction.

Owing to the important position of Khartoum, it is of interest to summarise records of *A. aegypti* in the town. Balfour (1904), after starting the control of *A. aegypti*, wrote that it had not been found breeding much but that some infestations might have been undetected. In 1906 he wrote " *Stegomyia fasciata* has given up the struggle and, as far as can be told, has not been present for many months. It used to be a nuisance in the middle of the day". He (Balfour, 1908) stated that mosquitos were rare and chiefly species of *Culex* but that *A. aegypti* had occasionally reappeared although it had never regained a footing in the town. H. H. King recorded the species in September 1909 (Government files) and Archibald (1917) recorded it as prevalent ; it was again reported in September 1938 and December 1939. Since then careful inspections have failed to yield *A. aegypti*. It seems probable that at Khartoum, which is on the southern border of a desert tract



Map 1.—Showing where *Aëdes aegypti* has been found in the Sudan and (inset) the percentage of villages found infested in areas (indicated by map squares grouped as explained in the text) examined by the Headquarters Aëdes Inspection Unit.

unfavourable to the species, *A. aegypti* has never been very abundant and has been eradicated, to reappear on infrequent occasions and be rapidly destroyed.

A. aegypti has very seldom been found in trains.

From a consideration of the house indices in many villages, it appears that the existence or degree of prevalence of *A. aegypti* among the settled population can usually be attributed to the influence of one or more of three factors. These factors seem to afford such a satisfactory explanation of distribution in most cases that

they appear to be worth comment. They are: (1) scarcity of water, (2) what may be termed "prosperity without culture", in places with low or high rainfall, and (3) high humidity. Occasionally special circumstances explain prevalence.

Scarcity of water is an important factor in many places since water supply is one of the main problems of the Sudan. Where housewives have to clamber hundreds of feet down hot rocky hillsides to fetch water from a small trickle in the dry season (as in parts of the Nuba Mountains) or walk miles to get it, they naturally tend to store it carefully. In some areas donkeys are used to fetch water and there is less storage. Water scarcity tends to cause *A. aegypti* to abound in such regions as the sandy areas of Darfur and Kordofan (the western central area in map 1) and conversely the mosquito is found in few villages along northern rivers and in the Gezira irrigation scheme.

"Prosperity without culture" is a factor operating at a certain stage in social development. A very poor man may possess no water-containers and drink from a stream or pool. A less poor man may have one small earthenware water jar that is emptied and then taken out to be re-filled. A man with more belongings may possess several jars in his hut or a jar with a gourd for fetching water, and the jar that remains in the hut could breed *A. aegypti*. Examples are sometimes seen in the headman of a village whose house is the only one containing *A. aegypti*, or in migrant labourers who have suddenly earned higher wages than before, settled near a town, and bought many utensils. People of this standard are likely to possess enough jars to store sufficient water for indoor breeding or to catch rain water in rainy areas. People with a higher standard of living than these create more potential breeding places. Examples are seen in large towns and in houses with many rooms and with water tanks, animal drinking troughs, flower vases, garden tree-holes, servants' water jars, etc. In these cases the tendency to form numerous breeding places is counteracted by "culture" in the shape of public health services, piped water supplies and good house-keeping. A somewhat similar state of affairs is seen by comparing a sea-going Red Sea dhow (sambuk) (a type formerly teeming with *A. aegypti* var. *queenslandensis*) and a Nile steamer with its high standard of cleanliness. *A. aegypti* was generally scarce in the Nuba Mountains (Lewis, 1943), evidently because most of the people led a simple life and few possessed many jars for storing water in the dry season or collecting water in the rains.

High humidity presumably operates by lengthening the life of the adults so that many gravid females are present when opportunities for egg-laying occur. High atmospheric humidity may be the reason for the fact that the coastal towns would probably have a house index of 100 per cent. (var. *queenslandensis*) if no control were exercised, and the dryness of the desert atmosphere may make the area north of Khartoum unsuitable for the species. Beeuwkes and others (1933) found that at Gadau, in Northern Nigeria, with a less hot and dry climate than places north of Khartoum, conditions appeared to be really favourable for the breeding of *A. aegypti* only during the rainy season.

Various special circumstances have promoted the breeding of *A. aegypti*. Elderly people living alone sometimes store water and can not clean their houses. In some *aegypti*-infested villages (Tagoi area) of the Nuba Mountains, the insect breeds in enormous jars which are probably a relic of the days when the hill-dwellers were besieged by people from the plains. War-time conditions increased the breeding of *A. aegypti* in some places. In one area control was interrupted by enemy action, and in another the construction of extra wells for military use resulted in the failure of other wells and consequent storage of water; in another area an influx of refugees had a similar result, whilst elsewhere the presence of thousands of empty petrol tins created a problem. In many areas the scarcity of cloth made it difficult to enforce the covering of water jars.

A factor which probably contributes to the rarity of *A. aegypti* north of Khartoum is the low temperature of domestic water jars in winter. These are usually porous earthenware coolers in which the water temperature approaches that of the wet bulb thermometer, which is very low at night in the winter.

Dhows afforded very favourable breeding places for *A. aegypti* var. *queenslandensis* before the control of this species was undertaken in these craft at Port Sudan. Good breeding places were provided by the large open drums in which water was carefully stored. The crew provided a ready food supply and the adult mosquitos rested in the large space, left amidships when the cargo is stored, where evaporation of bilge water and spray gives rise to humid conditions.

Notes on Bionomics.

As far as is known the variety does not differ in its behaviour from the type form.

Neither larvae nor adults of *A. aegypti* have been found by the writer more than a few hundred metres from houses. In the dry season in the central Sudan adults are uncommon in houses unless the larval house index is high, perhaps from 50 to 100 per cent. This is not surprising if dryness of the air is responsible for the scarcity of *A. aegypti* in the north of the country, and in view of the findings of Beeuwkes and others (1933) in Nigeria. At Wad Medani a colony of *A. aegypti* is kept in a cage exposed to atmospheric conditions but breeding continues throughout the year because a cool damp resting place is provided for the adults. This consists of a flower-pot half full of water with a cage placed over the water and open at the top. Large numbers of adults rest in the cage which prevents them from laying eggs in the flower-pot.

The inspection of water jars has revealed the presence of many aquatic animals, including a number of predacious forms, Notonectid bugs, larvae of *Culex tigripes* and (in one tribal area of the Nuba Mountains) terrapins which destroy many larvae of *A. aegypti*. At Jebelein small predacious fish (*Micralestes acutidens*, Peters) were found in river water kept in jars for animals.

Other Species of the Subgenus Stegomyia.

Even where species of *Stegomyia* are common in the rains, it has been found difficult to obtain larvae from dust collected at random from tree-holes in the dry season, possibly because many holes are drained by invisible cavities inside the trunks. Much time may be wasted therefore in the dry season, in filling holes which appear to be potential breeding places. *A. vittatus* can easily be bred from dust from shaded rock pools.

A. simpsoni var. *lilii*, although common in many areas with annual rainfall of over 400 millimetres, where plants with suitable axils occur, is abundant in few places. It has been found infected with yellow fever in nature by Mahaffy and others (1942).

A. metallicus is the most widely distributed and commonest of the tree-hole-breeding species. It is not uncommonly found breeding in domestic water jars though these are an unusual habitat. It occasionally bites indoors but usually feeds near its breeding places in the evening. *A. luteocephalus* is less common than *A. metallicus*; it also bites in the evening near its breeding places.

A. unilineatus has been found by H. H. King (note in Government files) attempting to bite at dusk at Jebelein, but was never found biting by the writer in the Nuba Mountains among mosquitos caught biting in the evening and by day although larvae were common. It has, however, been seen biting man indoors in the afternoon at Erkowit in June and July and may be a diurnal biter. Mr. W. Ruttledge observed males swarming round people's legs indoors at Erkowit.

The dragon-fly nymph which preyed on the larvae of *A. vittatus* in the Nuba Mountains has been identified as the common species *Crocothemis erythraea*, Brullé. The swarming habit of the males of *A. vittatus* noted by Lewis (1943) has also been observed by Ruttledge at Erkowit.

Species of the Subgenera Aëdimorphus, Banksinella and Diceromyia.

The females of most of the species that are known to bite man have been seen to do so about dusk but do not appear to start at a definite time as do some of the swamp-breeding species of *Anopheles* and *Culex*. *Aëdes argenteopunctatus* has been observed biting by day and night and *A. albothorax* by day (at Suki). Haddow (1945) considered that in Uganda *A. circumluteolus* was mainly diurnal but a catch at Abu Zur (recorded below) indicates that in at least part of the Sudan it is very active at night. Caught adults of *A. taylori* and *A. furcifer* vary considerably in size.

Owing to the difficulty of identifying females of some species of *Aëdimorphus* several records have been ignored in compiling Table II. The list of biting species will probably be increased.

Culex.

Bauer (1928) experienced great difficulty in feeding *Culex nebulosus* on man and monkeys, and Kerr (1933) rarely found it on man although larvae were abundant. Davis & Philip (1931) found that it bit chickens in West Africa. Although *C. nebulosus* is abundant in some parts of the Sudan it has never been seen to bite man. It is probable that in this country if it does so at all it is only very rarely as an exception to its normal habit.

C. poicilipes is one of the commonest outdoor man-biting Culicines in the country, except among hills. It feeds mainly by night but has been found biting at all times of day.

C. duttoni is noteworthy for the frequency with which its larvae are found in domestic water jars. It is thought to lay eggs indoors but evidence on this point is required. Kerr (1933) found one specimen on man at night during many hours of catching.

C. univittatus is a very common species. The writer has lived for ten years in an area where it is common and has only seen it bite man on one occasion, when two females bit out of doors. It is thought that these may have been hybrids between the species and var. *neavei* or specimens of *univittatus* with aberrant feeding habits. It is even possible that the mosquitos may have been examples of var. *neavei* with an unusually large number of pale scales making them resemble the type form. At the Gezira Research Farm (an irrigated area of about 1,000 acres near Wad Medani, Paris green (which does not kill Culicine larvae) with good floating properties has been used instead of oil for the control of *Anopheles gambiae* for the last nine years. Residents, of whom three are entomologists, were asked to report any cases of Culicines biting. Hundreds of thousands of *C. univittatus* must have bred but only a few Culicines, all *C. poicilipes*, have been observed to bite.

Adults of *C. univittatus* are sometimes found in houses by day. Males were seen swarming at dusk over a wide well at Rashad on 31st January, 1941. They rose in the air at the sound of the human voice.

C. univittatus var. *neavei* breeds at the edges of swamps and has been found biting man on several occasions near its breeding place.

C. pipiens subsp. *molestus* breeds in pools, wells, ditches and pit latrines and has been found biting in houses by day and night and on steamers. This is probably the mosquito referred to as *C. fatigans* in Khartoum by Balfour (1904) whose account shows how troublesome it can be if not controlled.

C. fatigans has a restricted distribution and is so well under control that it has seldom been observed in the adult stage.

C. antennatus bites man after sunset near its breeding places and some have been seen biting man by day on a steamer in the Sadd in July. It sometimes clusters round light on steamers. Haddow (1942) found in Kenya that few visited a hut occupied by a human being at night, but that a huge number entered one occupied by a calf. A recent catch at Kosti suggests that in the Sudan also this species greatly prefers cattle.

C. decens, a common species in the southern Sudan, has been shown by Davis & Philip (1931) to bite chickens in West Africa.

Notes on the Mosquitos of each Area of the Sudan.

Faunal Areas.

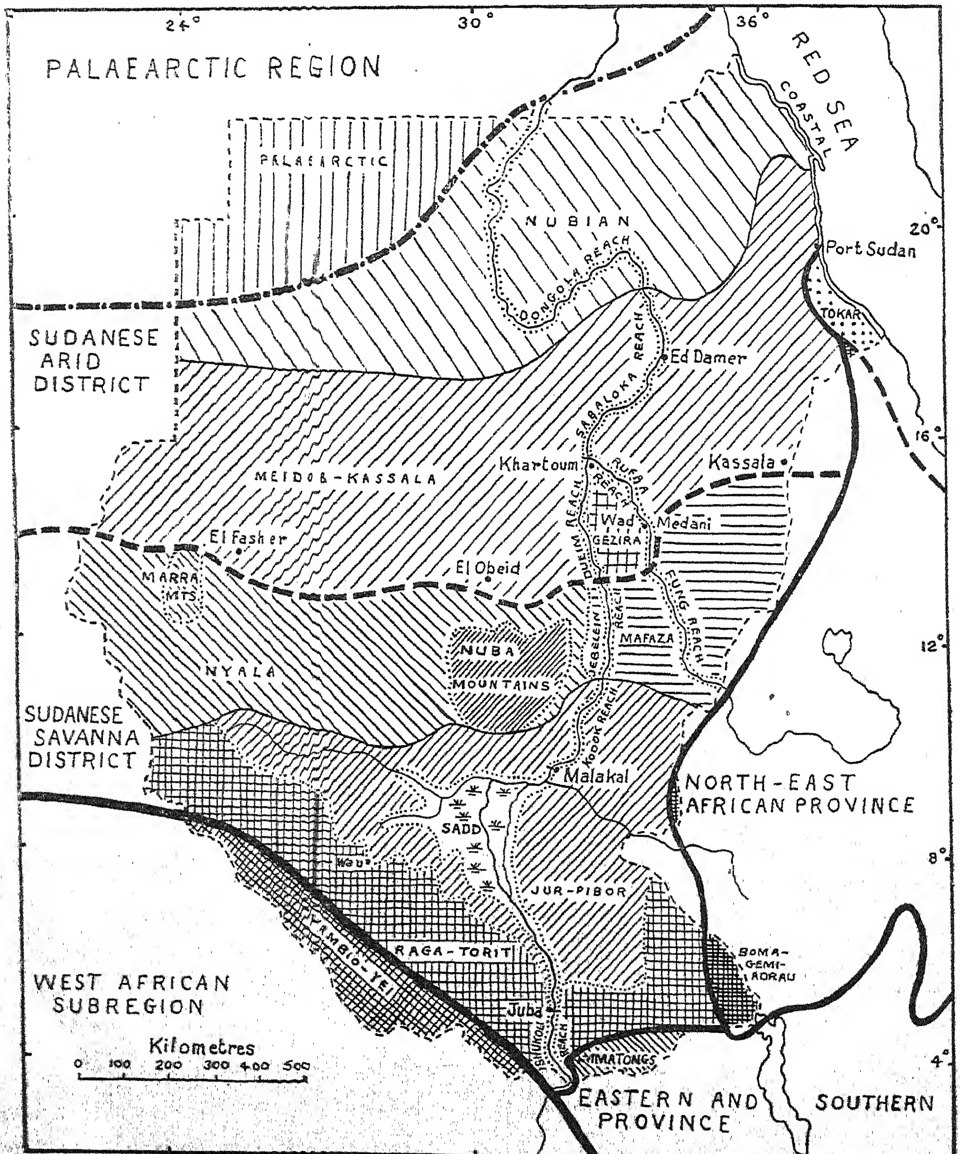
In considering the mosquitos of the Sudan, with its area of nearly a million square miles, it is convenient to select natural divisions of the country in the shape

TABLE III.

The areas in map 2 shown in relation to the faunal districts of Chapin which have been slightly modified as indicated in the text.

Faunal areas of Chapin*				Areas of the Sudan	
Region	Sub-region	Province	District	Sub-district	Area
Palaearctic					Palaearctic
Ethiopian	East and South African	Sudanese	Sudanese Arid	Northern Arid	Nubian Dongola reach
				Southern Arid	Meidob-Kassala Sabaloka Reach Dueim Reach Rufaa Reach Gezira
			Sudanese Savanna	Northern Savanna	Nyala Mafaza Marra Mountains Nuba Mountains Jebelein Reach Fung Reach
				Southern Savanna	Jur-Pibor Kodok Reach Sadd Raga-Torit Shukoli Reach
		North-east African	Abyssinian Highland Somali Arid		Boma-Gemi-Adrau Tokar
		Eastern and Southern	East African Highland		Imatongs
		Guinean Forest	Ubangi-Uelle Savanna		Yambio-Yei
	(Coastal Area)				Coastal

of sub-divisions of the recognized faunal areas. Chapin (1923) discussed previous work on zoological divisions of Africa and mapped avifaunal areas. Lynes (1925) proposed some modifications with particular reference to the Sudan and Bowen (1926) gave a map of the Sudan based on Chapin's and Lynes's work with two modifications, one of which was the marking off of the Sadd Area from the rest of the Sudanese savanna. Chapin (1932) modified his previous map and referred to the desirability of making further sub-divisions in dealing with special portions of the continent. Whitfield (1933) gave a map in which the 400 millimetre isohyet



Map 2.—Areas of the Sudan selected for descriptive purposes shown in relation to zoogeographical districts, the boundaries of which have been slightly altered. See also Table III.

divided the Sudan into northern and southern halves, and Edwards (1941) reproduced Chapin's map of 1932 and discussed the distribution of some Sudan mosquitos. In map 2 the main areas are based on Chapin's 1932 map of Africa, but the division between the arid and savanna areas is altered to approximate to the 400 millimetre isohet, and the limits of the Eastern and Southern and of the North-East African Provinces are somewhat changed. The sub-districts and smaller areas are designed for use in the present paper and are based on the distribution of mosquitos and certain other insects and on various features of the country. Most of the Sudan forms part of the Sudanese savanna and Sudanese arid districts, and each of these is further divided into two belts running east and west.

The Sudan, in general, slopes downward from south to north. An important topographical feature is a vast area of alluvium extending from Juba to a point north of Khartoum, which, in Pleistocene times, was probably a series of swamps. The mild climate of the south gradually gives place to the desert conditions of the north where there is great heat in summer, low temperatures (with rare frosts at Wadi Halfa) in winter, a negligible rainfall, and low atmospheric humidity. In the south the rainy season lasts from about April to October and in the central area from about July to September. On the coast there are winter rains. In much of the central Sudan, owing to the sparseness of the vegetation and the seasonal rainfall, much of the rain water runs quickly downhill so that there are numerous temporary swamps in the rainy season and dry water courses in the dry season.

In several areas an indication of the prevalence of species was obtained by catching mosquitos biting. They were usually caught on one person by himself with a suction catcher. Except in a catch at Abu Zur, when additional time was taken to allow for that lost in killing specimens, some catching time was lost in this process. Nevertheless the great abundance of mosquitos in several places will be noticed, as at Kosti, where some 400 were caught in half an hour. Haddow (1945) writes of 20 catchers sometimes taking this number in a whole hour in the Bwamba Forest in Uganda.

The greatest rate of catching over a short period was at Rahad where some 160 were taken in five minutes.

The distribution of *Aëdes aegypti* is not considered in this section as it has been described above.

The Yamboi-Yei and Raga-Torit Areas.

Many streams flow towards the great swamps. The existence of small inland papyrus swamps in some areas is interesting because in most parts of the Sudan mosquitos almost disappear in the dry season and it is difficult to understand how yellow fever can remain endemic in the country except in areas where many mosquitos can breed during all or most of the year. In the rains tree-hole-breeding mosquitos and *A. vittatus* are common near Juba. Potential breeding places of *A. simpsoni* var. *lilii* are provided in some areas by banana trees, pineapple plants and *Colocasia* sp. During a visit to the Sources Yubu-Meridi area in December 1941, *T. uniformis* was seen biting in many places both near and far from houses and there were many small swamps, some with papyrus, along the smaller streams. Culicines found biting less commonly were *A. cumminsi*, *A. circumluteolus*, *T. africanus*, *T. cristatus* (which bit in a hesitant manner and was easily disturbed) and *C. poicilipes*. *A. simpsoni* var. *lilii* was breeding in banana and pineapple plants at Meridi.

The Imatongs and Boma-Gemi-Adrau Areas and the Shukoli Reach.

Little collecting has been done in these relatively small areas, parts of which are uninhabited.

The Sadd Area.

This is an area of vast permanent and seasonal swamps, swarming with countless mosquitos. It lies within the yellow fever area and is one of the most northerly parts of the Sudan where mosquitos exist in large numbers throughout the year. The northern end of the area is near the Nuba Mountains of which one hill is within sight of the swamps. Many steamers pass through the Sadd (pronounced sudd) on the way to areas free of yellow fever in the north. The Sadd consists of swamps, largely overgrown with papyrus, and, at the edges, of grass swamps which are flooded at the high river period ; the area varies from month to month and year to year, and the area flooded in a normal year has been estimated (Butcher, 1938) at about 45,000 square kilometres, of which the Bahr el Jebel swamps, in which most collecting has been done, comprise some 7,000 square kilometres. The name means a barrier in Arabic and originated in the days before machinery was available to clear a passage through the masses of floating vegetation. There are several islands of permanently dry land.

The area is inhabited by people of cattle-owning Nilotic tribes, who live inland during the rains and bring their cattle to the river in the dry season where to protect the cattle from the swarms of mosquitos they make smudge fires which are a conspicuous feature of the landscape. In some areas the cattle sleep in stables of a circular type with a fire centrally over which the men sleep in a cloud of smoke that fills the whole building. In the south there are several permanent villages among trees on the river bank and in the north some traders' posts (such as Adok) on landing stages in the swamps, places at which yellow fever might perhaps occur (as at Malakal as noted above). It has been estimated that some 15 cubic kilometres of water are lost, mostly by evaporation, each year from the Bahr el Jebel swamps (Hurst, 1944) and the construction of a canal has therefore been planned that will take much of the water past the swamps and save it for irrigation. This will, of course, have a great effect on the mosquito fauna.

Sixty-three species, subspecies and varieties of mosquitos have been found in the Sadd area. Sixteen of them are species of *Aëdes* which breed in the rainy season and of the other 47 most are swamp breeders. Common Culicines in the seasonal swamps are *Uranotaenia balfouri*, *Ficalbia splendens*, *F. lacustris*, *F. mimomyiaformis*, *F. uniformis*, *Taeniorhynchus africanus*, *T. uniformis*, *Culex poicilipes* and *C. univittatus*. In the permanent swamps fewer species are readily found but *Aëdomyia africanus*, *T. uniformis* and *C. antennatus* are common. The writer has collected mosquitos in many parts of the Sadd area in the winter (Table IV) and on a single steamer journey during the rains (Table V).

In the winter the great majority of Culicines taken in evening catches (93 per cent.) were *T. africanus* and *T. uniformis* which were often very numerous, in one place 158 being collected in 15 minutes by one person on himself. *C. antennatus* commonly bit man. A 25-minute catch by two people from cattle at Malakal on 8th December 1940 yielded 255 mosquitos which included 81 *T. africanus*, 6 *C. poicilipes* and 126 *C. antennatus*. The relatively small numbers of *C. poicilipes* in adult catches were surprising in view of the prevalence of its larvae. In the permanent papyrus swamps of the northern Sadd *T. uniformis* could easily be collected at dusk among the vegetation but species of other genera did not appear to be abundant, possibly owing to the presence of the cyprinodontid fish, *Epiplatys marni*, Stdr., and the Cichlid, *Haplochromis multicolor*, Schoeller.

At the beginning of the rainy season (Table V) the most striking feature of the catches was the immense numbers of *C. antennatus* which comprised 78 per cent. of the specimens of the 13 species of Culicines collected. The 332 remaining on the steamer on 10th July, for instance, were a mere remnant of tens of thousands which had come aboard in clouds on the previous evening, biting in all parts of the vessel. The presence of several species not found in the winter may be noted.

TABLE IV.

Adult mosquitos collected in the Sadd Area in December and January and between Malakal and Melut in December (percentages in italics).

Species	Biting man after sunset: All catches, each of ½-hour or less		Biting man after sunset: One 15 minute catch 121 kms. up Bahr el Zeraf 14.i.40		Outside house screening in evening		In unscreened houses by day		In steamers and accompanying barges by day†		Biting man after sunset between Malakal and Melut	
Anopheles coustani var. *ziemanni* ...	50	*33*	11	*5*	44	*15*	1	*0·2*	5	*1*	13	*1*
A. nili	—	—	—	—	—	—	—	—	—	—	2	*0·2*
A. funestus ...	4	*0·3*	—	—	111	*37*	546	*93*	438	*82*	1	*0·1*
A. wellcomei ...	95	*6*	25	*12*	4	*1*	5	*1*	56	*10*	6	*0·6*
A. gambiae ...	—	—	—	—	1	*0·3*	7	*1*	2	*0·4*	—	—
A. rufipes	—	—	—	—	1	*0·3*	1	*0·2*	—	—	—	—
A. pharoensis ...	4	*0·3*	—	—	11	*4*	3	*1*	—	—	8	*0·8*
Aëdomyia africana	—	—	—	—	3	*1*	—	—	3	*1*	—	—
Taeniorhynchus metallicus ...	—	—	—	—	1	*0·3*	—	—	2	*0·4*	—	—
T. africanus ...	179	*12*	54	*25*	58	*19*	11	*2*	20	*4*	400	*46*
T. uniformis ...	1,063	*70*	104	*48*	15*	*5*	8	*1*	9	*2*	508	*52*
Culex poicilipes ...	10	*1*	2	*1*	2	*1*	—	—	—	—	14	*0·1*
C. antennatus ...	105	*7*	20	*9*	52	*17*	—	—	—	—	17	*0·2*
C. spp.	—	—	—	—			5	*1*	2	*0·4*	—	—
No. of mosquitos ...	1,510		216		303		587		537		969	
No. of collections ...	14		1		6*		14		9		5	

* Five at Malakal.
† Most catches in steamer which stopped more frequently than most.

Little is known of seasonal changes in numbers of mosquitos in the main swamps but from the few catches made in July it would appear that in the southern area, where much drying occurs at low river, there is a great increase in the rains, but that in the northern part there is no great change.

In the dry season most of the Culicines carried on steamers, nearly all on the lower deck, were *T. africanus* and *T. uniformis*. An adult of the former was seen to travel for several hours by day resting on the rudder post on the outside of the stern of a steamer. Many of the specimens of *Anopheles wellcomei* collected were found just above water-line between a steamer and a barge made fast to it. The finding of *Aëdes luteocephalus* on a steamer in July is of interest. Not many mosquitos appear to board steamers in motion except when immense numbers occur in the southern Sadd in the rains. In the permanent papyrus swamp it seems possible that the height of the papyrus may prevent mosquitos drifting on the wind towards steamers. Owing to the difficulties of navigation vessels often remain for some time alongside the swamp vegetation.

TABLE V.

Sample catches made in a steamer and accompanying barges between Juba and Kosti.

July, 1945	9th	10th	11th	12th	13th	14th	15th	
Approximate position at midnight preceding	Lado (stopped for night)	Lake Pauvendal	Lake Jur	100 kms. up-stream from Lake No	Malakal	Jebel Ahmed Agha	Kosti Bridge	Total
Anopheles coustani var. *ziemanni* ...	—	13	—	1	1	—	—	15
A. nili	2	1	5	8	—	1	—	17
A. funestus	—	—	1	—	—	—	—	1
A. gambiae	105	2	—	—	1	1	—	109
A. pharoensis	29	—	—	—	—	—	—	29
A. squamosus	1	—	—	—	—	—	—	1
Ficalbia hispida	—	—	—	1	—	—	—	1
Taeniorhynchus africanus	—	13	4	—	1	2	—	20
T. uniformis	—	8	2	2	4	6	1	23
Aëdes luteocephalus	1	—	—	—	—	—	—	1
A. circumluteolus	—	—	3	—	—	—	—	3
A. taylori	—	—	—	—	—	—	1	1
Culex tigripes	—	1	—	—	—	—	1	2
C. poicilipes	—	21	7	—	2	—	2	32
C. duttoni	—	—	—	1	—	—	—	1
C. univittatus	—	—	3	1	—	—	2	6
C. univittatus var. *neavei*	—	16	67	2	2	3	—	90
C. pipiens	—	—	—	4	—	1	—	5
C. antennatus	4	332	160	43	16	13	3	571
C. decens	1	—	—	—	—	—	—	1
Total	143	407	252	63	27	27	10	929

The Kodok Reach.

One of the landing stages in this reach is at Kaka to which cotton is brought from the Nuba Mountains by road for shipment to the north. In the event of another epidemic of yellow fever in the Nuba Mountains, Kaka might possibly be a source of infected mosquitos for north-bound steamers.

Along the river in this reach there is a flood plain, usually several hundred metres wide, which forms extensive mosquito-infested swamps during the high river period. Species of mosquitos caught biting are shown in Table IV. During the low river period mosquitos probably breed in a few pools and among umm suf grass (*Vossia cuspidata*, Griff.) floating on the edge of the main stream. At this time (April 1945) the writer travelled by steamer from Jebelein to Malakal without finding any mosquitos on board except two specimens, *T. uniformis* near Jebel Ahmed Agha and *Anopheles funestus* near Malakal.

The Jur-Pibor Area.

This is a vast area with few inhabitants and few trees. In the dry season it is mainly waterless but in the rains it is flooded with shallow water derived from rain, from the flooding of Nile tributaries, and from the Nile itself. The tributaries are largely swampy and have a mosquito fauna closely resembling that of the Sadd.

The Jebelein Reach.

Most of this area is affected to some extent by the Jebel Auliya Dam. In the south the area resembles the Kodok Reach, but north of Jebelein there is a transition to the type of swamp seen in the Dueim Reach which is described below. Table VI indicates the difference between adult catches in the Jebelein and Dueim Reaches. Jebelein is the most northerly area on the White Nile where *A. funestus* is abundant. *T. africanus* occurs but is outnumbered by *T. uniformis*.

TABLE VI.

Mosquitos collected while biting after sunset near breeding places by one person at Kosti, Jebelein and Rahad (percentages in italics).

Species	Kosti, three ½-hour catches, November and January		Jebelein, one ½-hour catch in January		Rahad, three catches in December, totalling 25 minutes	
Anopheles coustani var. *ziemanni*	61	*7*	77	*32*	85	*22*
A. nili	—	—	1	*0·4*	—	—
A. wellcomei	119	*10*	2	*1*	—	—
A. pharoensis	434	*47*	17	*7*	78	*20*
Taeniorhynchus africanus	—	—	3	*1*	2	*1*
T. uniformis	2	*0·2*	98	*40*	73	*19*
Culex poicilipes	287	*31*	3	*1*	145	*38*
C. antennatus	28	*3*	47	*19*	—	—
No. of mosquitos ...	931		248		383	

The Fung Reach.

On this section of the Blue Nile the bank on the inner side of a meander is usually composed of silt in the form of a basin. These basins are flooded to a varying extent each year by rain and flood water and are overgrown with *Acacia arabica* and swamp grasses. At the lower end of the reach is the Sennar Reservoir in which shallow swamps, thickly covered with the grasses *Echinochloa stagnina*, P. Beauv., and *Vossia cuspidata* (small variety), exist from July to March.

In the acacia groves, tree-hole mosquitos are common in the rainy season. *Aëdes metallicus* is a very common species and the others which occur are *A. luteocephalus*, *A. unilineatus*, *A. taylori* and *C. nebulosus*. Many grey monkeys, *Cercopithecus aethiops aethiops*, L., also occur, and since some individuals of the closely allied *C. a. centralis* can circulate yellow fever virus (Hughes, 1943) it seems probable that epizootics could occur in the rainy season if the virus were introduced.

At Singa, where there are many trees near the town, the monkeys often come near houses.

Mosquitos of many species breed in the swamps, by far the most numerous in the Sennar area being *A. pharoensis* and *C. poicilipes*.

In several parts of the area species of *Aëdes* which breed in ground water are common at the beginning of the rains. At Abu Zur on 26th August, 1945, at 22.30 hours, the writer collected the following on his legs in half an hour :—

Anopheles coustani ...	8
Taeniorhynchus uniformis	2
Aëdes (*Aëdimorphus*) *argenteopunctatus* ...	37
,, ,, sp. (*cumminsi* or ally)	111
,, ,, *fowleri*	3
,, (*Banksinella*) *circumluteolus*	194
Culex univittatus var. *neavei*	1
	356

The Mafaza Area.

This area consists largely of thorn scrub growing on a nearly level clay plain, and contains three tributaries of the Blue Nile, the Dinder, Rahad and Atbara. During the rains numerous swamps form and much of the area becomes infested with horse flies (Tabanidae) which are an important cause of the migration of owners of cattle and camels to the drier country to the north. Collections made at Hawata on the Rahad in December showed that many mosquitos were breeding in a river-side swamp, and *T. africanus* and *T. uniformis* were seen biting. Mr. W. Ruttledge has found *Aëdes* sp. (*taylori* or *furcifer*) biting viciously after dark at Abu Kidada in October.

The Nyala Area.

Much of this area is covered with thorn scrub growing on sandy soil and, as in the Mafaza Area, large parts are infested in the rains with Tabanids which drive animal owners northward. Many swamps form in the rains but usually dry up each year. The writer has visited three of these, Lake Keilak and the swamps at Rahad and Geibat. They are all devoid of the larva-eating cyprinodontid fishes, *Aplocheilichthys loati*, Blgr., and *Epiplatys marni*, Stdr., which are common in the White Nile. Lake Keilak was partly overgown in December with *Echinochloa stagnina*. Many *T. uniformis* and a few *T. africanus*, *C. poicilipes* and *C. antennatus* were found biting. The swamp at Geibat was open water in December 1940 and is said to be overgrown only in years when the water rises slowly.

Rahad is of particular interest in relation to yellow fever because it is at a point where an important road from the Nuba Mountains meets the railway. The large swamp near the town, which occasionally persists from one rainy season to the next, is largely overgrown with *Acacia* and aquatic vegetation, but there is no *Pistia*. It produces great numbers of mosquitos including several tree-hole breeders ; on one occasion 158 mosquitos were caught on one person in five minutes. The biting species are shown in Table IV. *Aëdes hirsutus* has been seen biting in July before the swamp filled. In December the common mosquitos in buildings by day were *A. rufipes* and *C. univittatus*. Umm Ruwaba is another railway station near a large swamp.

In many parts of the area water supply is a problem in the dry season, and near El Nahud it is stored in large holes made for the purpose in baobab trees (*Adansonia digitata*). These have an average capacity of 350 gallons and some large trees hold 2,000 gallons (Grabham, 1924). *Aëdes metallicus* has been found breeding in these holes in September before they are covered over. It is said to bite people by day when they cultivate near the trees and to be so common that it has been given a name, *abu ki 'an*, meaning " father of stripes " in Arabic.

The Nuba Mountains Area.

The mosquito fauna has been discussed by Lewis (1943) in relation to the 1940 epidemic of yellow fever. The combination of several factors seems to make the area suitable for extensive epidemics if many of the people are non-immune and if the virus is present in man or man-biting mosquitos at the beginning of the rains. The primitive way of living of the people (who, until a few decades ago, were obliged to live in the hills owing to the attacks of stronger tribes) is such that they are scattered among the rocks and trees in which the potential vectors breed. Instead of using wooden oil presses worked by animals they grind sesame on the rocks and so make, and have made, numerous breeding places for *Aëdes vittatus* near their houses. The degree of rainfall is suitable for the growing of sesame and the breeding of rock-hole and tree-hole mosquitos, and is sufficiently low for great areas of rock to be exposed in which the grinding holes are made. *Aëdes taylori* and *A. furcifer* fly further than most members of the *Stegomyia* group and the prevalence of these vectors in the area may spread the disease rapidly.

With regard to the future, it is to be hoped that the conditions resulting from peaceful government will lessen the risk of yellow fever outbreaks. As more people come to live in the plain they will be further from the breeding places of *A. vittatus* and may take to grinding sesame in stones in their own houses or in wooden oil presses. They will probably fell trees near villages so that tree-hole mosquitos will breed far from houses.

The Marra Mountains Area.

These mountains rise to a height of over 10,000 ft. and several streams run in the valleys. *C. arbieeni*, *C. ethiopicus*, *C. univittatus*, *C. sinaiticus* and *C. pipiens* are common in some places but no Culicines have been found biting.

The Meidob-Kassala Area.

This is a large semi-desert area containing three towns lying on important lines of communication (map 2). There is a bus route between Eritrea, where immunity to yellow fever has recently been recorded (Sams, 1944) and Kassala. *Aëdes arabiensis* and other mosquitos breed in the short rainy season in the southern part of the area, and *C. fatigans* is not uncommon near Kassala.

The Dueim Reach.

This reach, most of which is in the Jebel Auliya Reservoir area, is of particular interest because north-bound trains pass through Kosti which is a port for steamers (on which several potential vectors of yellow fever have been shown to travel further south) coming from the yellow fever area. This reach lies in a somewhat arid part of the country but the sedge, *Cyperus rotundus*, and the grasses, *Vossia cuspidata* and *Echinocloa stagnina*, exist and form extensive swamps when the water rises. Formerly sadd vegetation floated downstream on the flood but now, owing to the wide extent of the reservoir, this drifts ashore upstream of the Dueim Reach. The swamps are artificially flooded by the Jebel Auliya Dam from August to November. Table VI

shows that many swamp-breeding mosquitos occur, in one of the catches 398 specimens were taken in half an hour. The only abundant man-biting Culicine is *C. poicilipes* (Table VI). It is sometimes found in trains travelling from Kosti. *C. pipiens* subsp. has occasionally been found on steamers in the Dueim Reach. Below the dam, and near Khartoum, there is an acacia plantation part of which becomes a breeding place of *C. poicilipes* and other species in years when rain falls early and enables herbage to grow before the river rises.

The Rufaa Reach.

As on the Fung Reach many basins exist on the numerous bends of the river. In several near Wad Medani occur many monkeys and the tree-hole mosquitos found in the Fung. *A. metallicus* not infrequently breeds in houses in the town. In years when the river floods the basins there is a remarkable influx of swamp-breeding mosquitos which normally exist much further south. At such times *T. uniformis* and *C. poicilipes* have been found biting in the Wad el Magdub basin north of Wad Medani. *A. circumluteolus* has been found biting in considerable numbers in basins at Abu Geili and Wad Medani. In some basins *A. leesoni* subsp. *vera* and *C. perfuscus* breed at the beginning of the rains and the former bites man near the swamps.

The Gezira Area.

This area is nearly flat and consists of clay which is practically impermeable to water. Nearly a million acres are covered by the Gezira Irrigation Scheme and the remainder of the area is sparsely grown with grass or scrub. There is little natural drainage so that much rain water collects in shallow temporary swamps. In the irrigated area many of these are drained. In the dry season there is very little surface water except in irrigation channels, and, owing to control measures, very few Culicines breed in these. The common Culicines in the rainy season are *Aëdes scatophagoides, A. arabiensis, A. fowleri, C. tigripes* and *C. univittatus*, and several others occur over most of the area, but there is no abundant man-biting Culicine.

The Sabaloka Reach.

At Omdurman *C. pipiens* subsp. *molestus* has been found breeding in some pit latrines and wells, and sometimes bites people in houses.

The Tokar and Coastal Areas.

Much of the Tokar Area is dry but there are perennial streams and some trees in a few valleys, as near Erkowit. Here *Theobaldia longiareolata, C. laticinctus* and *C. sinaiticus* breed in large numbers in a stream in the dry season. In the rains *A. vittatus* is common, breeding in naturally hollow rocks, and *A. unilineatus* occurs. *C. fatigans* is sometimes found here and at Sinkat. In the coastal area *C. sitiens* and *C. fatigans* occur but are not abundant.

The Palaearctic and Nubian Areas and the Dongola Reach.

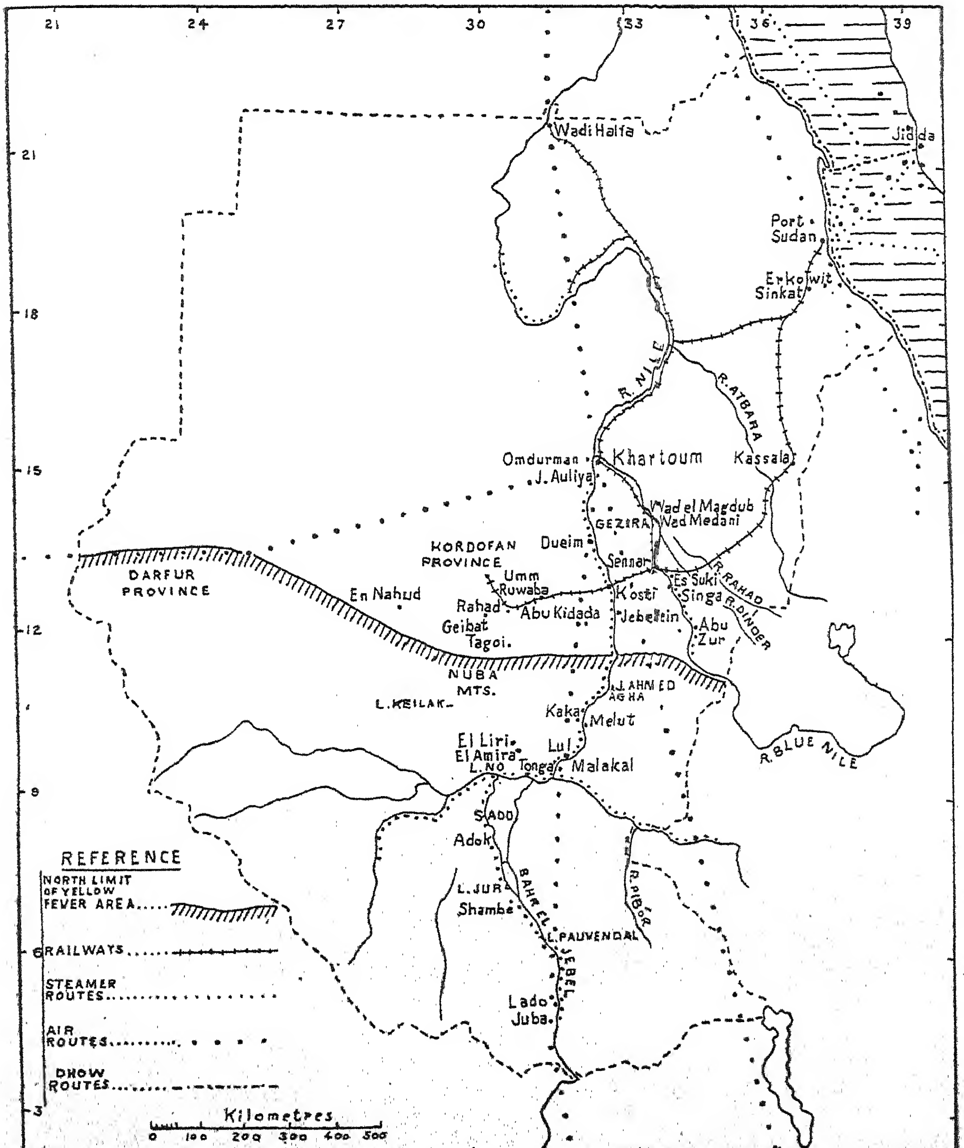
Away from the river the country is desert. Along the river near Wadi Halfa *C. pipiens* subsp. *molestus* and *C. univittatus* are common; the former breeds in outdoor breeding places and has been found in the larval and adult stages in steamers and biting in houses. *Aëdes caspius* used to bite people near the frontier but the breeding place has been controlled.

Control.

It appears that the mosquito control measures at present in force in the Sudan have had the effect, among others, of (1) rendering urban yellow fever epidemics with

A. aegypti as the vector impossible, (2) virtually exterminating *A. aegypti* in Khartoum, (3) very greatly reducing the number of mosquitos, particularly those with domestic breeding habits, carried on steamers, and (4) in general rendering very small the chance of yellow fever spreading north from the yellow fever area. Balfour (1904) referred to *Aëdes aegypti* as "*the great steamer mosquito*," whereas now it has not been reported in steamers for several years.

The foregoing paragraphs indicate the importance of maintaining the efficiency of the control measures. It is evident, for instance, that Culicines could travel from the area where yellow fever has occurred to Rahad, Umm Ruwaba, Kosti and



Map 3.—The Sudan, showing some important lines of communication and places mentioned in the text.

Sennar, and that others could travel by train from these places towards ports and aerodromes.

The objects of control are to prevent or limit epidemics and to prevent the disease from spreading. In most places the control of a rural epidemic would be extremely difficult. To prevent the spread of yellow fever, potential mosquito vectors are controlled in towns and villages along lines of communication so that any infection by an infected man or mosquito is likely to die out. Trains are sprayed in the rainy season before they reach Khartoum and Port Sudan. Steamers are sprayed en route by their crews and inspected by public health staff at the principal stopping places. The fact that mosquitos may travel on the outside of steamers and in the goods waggons of trains makes perfectly effective spraying practically impossible. In the Sadd area the steamer and health authorities have greatly reduced the number of mosquitos transported, but in an area where many thousands of mosquitos may board a vessel in a few minutes no measure short of abolishing river traffic would prevent all transport of mosquitos. Aircraft which fly northward or eastward from the Khartoum area or northward from Port Sudan are sprayed. Much use has been made of the work of Soper and others (1943) in planning control measures. The catching of adults to indicate hidden breeding places, however, is of little use in the northern and central Sudan owing to the general scarcity of adults at most times, as noted above. In many places the work is simplified by the fact that each house has only one room and a standard type of water jar. A detail found to be very important is the use of a small net for searching for larvae together with a dish for examining the contents of the net, each mosquito-man being supplied with a dish and net and a needle and thread for repairs. It has also been found important to check any tendency to report large numbers of inspections and to limit the number so that each house can be searched carefully. The control of *Aëdes aegypti* in towns and villages is part of the normal work of the Public Health Department and returns showing house indices of important places are sent monthly to the Director. The only employees engaged entirely on *Aëdes* work are an Aëdes inspection unit in each province (except the northern Province) and a headquarters unit which tours the whole country. Each unit reports indices to the medical inspector of the province, as does the headquarters unit, which is placed at his disposal when it visits the province. By comparing the monthly returns with the reports of the province units and these with the reports of the headquarters unit a useful check on the work is obtained. The various reports show the efficiency of the control at any time and old reports indicate places where control has proved difficult and where extra workers may be necessary.

Summary.

1. Owing to the history of yellow fever in the Sudan and the lines of communication which traverse the country, a general survey of the mosquitos, particularly the Culicines, is of practical interest. The known potential vectors of yellow fever are listed.

2. Observations on the man-biting or man-ignoring habits of some species are recorded and also notes on the bionomics of *Taeniorhynchus africanus*, *T. uniformis*, *Aëdes aegypti* and other species.

3. For purposes of description the country is divided into sub-divisions of the recognized faunal areas and notes are given on the Culicines of each.

4. Brief observations are made on mosquito control measures against yellow fever.

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THE USE OF RESIDUAL FILMS OF DDT AND GAMMEXANE IN MALARIA CONTROL.

By Major C. R. Ribbands, R.A.M.C.

These experiments form part of a series conducted by No. 2 Entomological Field Unit, R.A.M.C., to investigate new methods of using insecticides for malaria control. The results of experiments to determine the larvicidal effects of DDT have already been published (Ribbands, 1945, 1946b), and the experiments now recorded represent an attempt to determine optimum methods for using residual films of DDT and Gammexane in adult mosquito control.

The first section of this report compares the performance of various types of apparatus which have been used for the application of residual sprays, the second section is devoted to discussion of the relation between mosquito control and malaria elimination, and the third section records the effects of various treatments with DDT and Gammexane on mosquito infestation.

The experimental treatments were made possible through the most ready co-operation of the Manager of Hilika Tea Estate and the Superintendent and the Medical Officer of The Assam Frontier Tea Co., Ltd., and they were conducted with the willing and reliable aid of the members of No. 2 Entomological Field Unit, R.A.M.C., Sgt. J. A. Aspey, Sgt. R. E. Hawkins, Pte. R. E. Shaw and Pte. J. Sinclair. The tests of spraying apparatus were carried out by Pte. I. Jacobs.

Methods of Applying Residual Insecticidal Films to Dwellings.

(*a*) *Method of Experiment.*

The sudden advent of residual films of DDT as an important anti-malaria measure necessitated the conversion of existing apparatus for this purpose, and the tests now described were made in order to assess their relative merits.

Experiments were made to determine :—

1. The efficiency of the apparatus.
2. The diameter of the circle covered by the spray, at standard distances from a wall surface.
3. The output measured in cc. per minute.

To assess efficiency, measured quantities of kerosene were sprayed from known distances on to bed sheets hung vertically in a room. The sheets were weighed before and after spraying and from these data the percentage of the sprayed kerosene which had adhered to the sheets was calculated.

As a test of the margin of error involved in this technique, five experiments were made using the same Four Oaks Knapsack Sprayer at a distance of 2 feet. The percentage efficiency in the five readings was 63, 65, 68, 64 and 66 respectively, so the maximum deviation from the mean in these five experiments was 3 per cent.

These tests revealed that very high wastage occurred with some types of apparatus, but it is considered that they indicate the maximum efficiency of the apparatus when sprayed on to vertical surfaces and that the wastage is considerably greater when ceilings or inaccessible places are sprayed.

(*b*) *Air Pressure Sprayers and Flit Guns.*

In these experiments the performance of two motor driven air pressure sprayers was compared with that of a Mish air pressure flit gun and a Shelltox flit gun of ordinary pattern. The results are scheduled in Table I :—

TABLE I.

Comparison of Air Pressure Sprayers and Flit Guns.

Sprayer	Output cc. per minute	Percentage efficiency at distance of				Diameter of circle sprayed at distance of			
		6 in.	1 ft.	2 ft.	3 ft.	6 in.	1 ft.	2 ft.	3 ft.
Motor-operated Air Pressure Sprayers (De Vilbis and Paasche Airbrush)	45 to 115	53 to 66	45 to 51			10″	18″		
Air Pressure Flit Gun (Mish)									
(*a*) Fast pumping ...	42	92	74	49	21	2″	5″	8″	15″
(*b*) Slow pumping ...	31	96	86	40	13				
Flit Gun (Shelltox) ...	8	91	50	25	7	3″	6″	8″	20″

There was considerable inconsistency in the rate of output of the motor-driven sprayers in eight consecutive tests, each based on the time of emptying a full container. The rate of output also varied with the level of the fluid in the container.

All these sprayers were designed to produce spray mists and their operating principle was similar—the spray was atomised by a strong current of air, and the intermingled liquid and air delivered from the apparatus.

The experiments indicate that this principle was wasteful for residual spraying and resulted in low efficiency. This was because the finely divided particles of spray were mingled with a large quantity of air and were deflected with the air stream just before they reached the treated surface. The smallest globules were most readily deflected.

(*c*) *Oil Sprayers and Stirrup Pumps.*

Four types of pump were tested—Four Oaks Knapsack Oilers (direct air pressure action), a Solo sprayer (oil pressure, barrel pump), stirrup pumps, and a United States Army hand-operated pressure sprayer (which could be pumped up before use, and then carried by the operator). The last two types were equipped with nozzles and spraying arms of Four Oaks pattern, but the Solo sprayer had three different nozzles as supplied by the maker.

These results are appended in Table II, and comparison of them indicates that :—

1. The output was large in all cases, and varied between 500 and 1,000 cc. per minute.
2. Except in the Solo sprayer, the output was reasonably constant, and did not vary very greatly with the speed of pumping.
3. Their efficiency at 1 ft. from the sprayed surfaces averaged about 85 per cent., but it fell off to about 60 per cent. at 2 ft. in most cases and was very unsatisfactory at 3 ft. in all cases.
4. The highest efficiency was obtained at 6 ins. distance, but this distance was unsatisfactory because the area of the spray cone was much too small and the sprayed surface was drenched too quickly.

5. A reasonable compromise between efficiency and density of spraying was made when the nozzle was held 1 ft. from the wall, and 2 ft. was the maximum distance for economical use.

6. The Four Oaks nozzles were not exactly standardised, and three apparently similar nozzles, attached in turn to the same pump, had different performances—especially in relation to the area covered by the spray. This may have been a consequence of slight differences in the bore of the nozzle hole.

The results indicated that all of these four types of pump could be used satisfactorily for residual sprays. The Solo sprayer and the Four Oaks Knapsack Oiler both suffered two disadvantages in that they exposed their operators to greatest risk of contamination by leakage, and the rate of movement of their operators was restricted by the necessity for pumping so that only heaviest doses could be applied. The pumping action of the Solo sprayer, in addition, was rather arduous.

TABLE II.

Sprayer	Output cc. per minute	Percentage efficiency at distance of				Diameter of circle sprayed at distance of			
		6 in.	1 ft.	2 ft.	3 ft.	6 in.	1 ft.	2 ft.	3 ft.
Solo Barrel Pump Sprayer Maximum output:									
(*a*) Mist nozzle ...	500	93	93	78	40	6″	9″	14″	18″
(*b*) Lime nozzle ...	700	92	86	72	38	9″	14″	24″	36″
(*c*) Creosote nozzle ...	625	92	78	67	38	9″	14″	20″	30″
U.S. Army Hand-operated pressure sprayer:									
(*a*) Maximum output	950	90	80	62	44	10″	16″	28″	36″
(*b*) Minimum output	570	96	88	56	31	4″	8″	15″	20″
Four Oaks Knapsack Sprayer:									
(*a*) Maximum output	1,000	95	82	63	37	9″	18″	24″	36″
(*b*) Minimum output	700		87	72	46		12″	18″	24″
Stirrup pump (same nozzle as Four Oaks Sprayer)									
(*a*) Maximum output	940		83	69	40		15″	22″	32″
(*b*) Minimum output	520		86	56	33		11″	17″	22″
Four Oaks Knapsack Sprayer, same pump with three different Four Oaks nozzles: At maximum output—									
(i)	1,000	95	82	63	37	8″	18″	24″	36″
(ii)	950	93	84	67	36	9″	20″	30″	40″
(iii)	920	94	86	57	43	7″	10″	15″	20″

Stirrup pumps had the disadvantages that two men were required to operate them, that their output was slightly less constant, and that they required a long length of rubber hose, which perished rapidly on exposure to kerosene. They had the advantage that, with a graduated bucket container, the volume of solution used could readily be assessed and that their operators were least likely to be contaminated by the solution. Where high ceilings have to be sprayed extension pieces are necessary with all these types of apparatus.

Stirrup pumps were adopted for the experiments with residual sprays because of the advantage of easy measurement and their ready availability in military camps. They were fitted with locally made nozzles, designed on the simple principle common to Four Oaks and other makes of nozzle, and containing a filter, a spinner, and an aperture of the correct diameter.

(*d*) *Application of Standard Doses of Spray.*

All the apparatus tested showed such large variations in performance that it was impossible to apply consistently an exact dose even to a smooth vertical surface.

However, the following formula can be used to calculate approximate delivered doses :—

If a = output of sprayer in cc. per minute,

b = percentage efficiency of sprayer at distance of usage,

c = diameter in inches of the circle covered by the spray at that distance,

then a dose of 1 quart per 1,000 sq. ft. attaches to the wall surface when the nozzle is moved across it at the rate of $\frac{0{\cdot}00176\,a\,b}{c}$ ft. per second.

Calculations showed that for such a dose the required rate of movement of the nozzles of stirrup pumps and knapsack oilers would be 7·5–8 ft. per second, if held 1 ft. from the sprayed surface, or 4 ft. per second at 2 ft. distance. The rate of movement of the Mish gun would be 2·7 ft. per second at 6 ins. distance, or 1 ft. per second at 1 ft. distance.

It is not reasonable to expect an operator to move the nozzle of a Four Oaks Knapsack Oiler as quickly as 2 ft. per second because he is engaged in pumping at the same time and, therefore, the minimum dose that can be applied fairly evenly with this machine is 1 quart/400 sq. ft., at the extreme 2-ft. range, or 1 quart per 200 sq. ft. at 1-ft. range.

A stirrup pump operator, with an assistant for pumping, can move more quickly but the minimum dose that he can apply fairly evenly at 1 ft. range is 1 quart/400 sq. ft. The size of the spray globules also determines that such a dose is not far from the minimum limit for even application.

These considerations set a lower limit to the quantity of spray that can be evenly applied with such machines, and tests previously recorded have indicated that air pressure sprayers, fine droplets from which enable much smaller doses to be applied evenly, are mostly very inefficient and, because of their low output, very costly in labour time. Hence when light doses of residual insecticide are required the most convenient method is to dilute the solution used and this indicates one way in which water emulsions of insecticide offer advantages over oil solutions. It is probable, however, that heavy doses of insecticide will usually be found to be more economical than light applications.

Whatever pumping mechanism is used an output of 1,000 cc. per minute is as much as can normally be directed adequately by the operator and, therefore, motor-operated sprayers acting on similar principles would in any case possess only limited labour saving advantages over these hand-operated pumps. In localities where supplies of cheap but mechanically unskilled labour were available such advantages would usually be more than counterbalanced by their cost and complexity.

When spraying tea garden coolie lines, teams of three coolies (1 to apply the spray, 1 to pump, and 1 to carry supplies) using stirrup pumps, treating the whole of the inside wall and ceiling surface of the huts (average area=1,100 sq. ft. per hut) with a dose of 1 quart solution per 200 sq. ft., were able, under supervision, to treat 25 huts per day per team.

(e) *Conclusions.*

1. Sprays atomised and mingled with air were unsuitable for applying residual sprays because they were very wasteful in both material and labour.
2. Knapsack oilers and modified stirrup pumps were efficient. Motor driven sprayers of this type would offer only very limited advantages over hand-operated machines.
3. The wide variations in efficiency of various types of sprayer indicate that published records of experiments with residual sprays should differentiate between the quantity of spray used and the quantity which is likely to have adhered to the sprayed surface.

The Relation between Mosquito Reduction and Malaria Reduction.

The statistical basis of the use of residual lethal films must be appreciated before the effects of the treatments can be assessed. *Anopheles minimus*, Theo., normally finds its blood meals in a dwelling or shed, and the female usually rests for a time in the shelter in which she has found her host. Eight days is the minimum known incubation period for malaria within the mosquito (Strickland & Others, 1933).

A. minimus is believed to feed every second night (Thomson, 1941) and therefore not to become infective earlier than its fifth blood meal. Hence, if every dwelling and shed within flight range has been treated with a residual film of insecticide, the female *A. minimus* must survive this hazard four times or more before it can transmit malaria.

In Table III the corresponding values for various degrees of hazard and different numbers of entries are displayed and it is shown that, with a 50 per cent. risk of mortality per entry, the risk of mortality before the fifth entry is 93·75 per cent., with a 66 per cent. risk per entry the total risk is 98·8 per cent., and with a 75 per cent. risk per entry it is 99·6 per cent.

TABLE III.

Relation Between Cumulative Mortality Risk, Risk Per Entry, and Number of Entries.

Number of entries before entry for infective bite	Cumulative Mortality Risk					
	25% risk per entry	33·3% risk per entry	50% risk per entry	66·7% risk per entry	75% risk per entry	90% risk per entry
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	25	33·3	50	66·7	75	90
2	43·7	55·6	75	88·9	93·7	99
3 (=entry every third night)...	57·8	70·4	87·5	96·3	98·4	99·9
4 (=entry every second night)	68·4	80·2	93·7	98·8	99·6	99·99
8 (=entry every night) ...	89·4	96·1	99·6	99·99	100	100

These figures show that elimination of malaria transmission should be obtainable through the use of a partially lethal residual film of insecticide. The necessary minimum for this objective will depend upon the house haunting habits of the species to be controlled, but any treatment which is 75 per cent. lethal to a species

should leave ample margin for its complete control. The calculations presented in Table III take no account of two factors that may tend to invalidate them :—

1. Anophelines are local in their habits so that a single badly treated dwelling, close to a breeding ground, may be visited by the same Anopheline on several occasions, until it becomes infective and provides a local focus of infection.
2. It is possible that there are races or individuals concealed within some main vector species which have a less marked preference for indoor feeding and sheltering, and would be less exposed to the insecticide risk than the main bulk of their species.

These two factors should be more than outweighed by the following factors which would tend to decrease the transmission risk still more.

1. Mosquitos do not always become infected at their first blood meal and each additional meal would increase the hazard proportionally.
2. Most mosquitos live for a short time, but it is possible that the few which survive long enough to become infective would often survive until they had obtained several infective feeds (Russell & Ramachandra Rao, 1942). The hazard would increase proportionally with each feed, so the more frequently this normally occurs in nature the greater the reduction in malaria risk caused by the treatment.
3. Some *A. minimus* females enter dwellings for shelter only on nights when they do not feed (Thomson, 1941).
4. Mosquitos might possibly acquire sublethal doses of insecticide by ephemeral contact with the residual film and several successive entries might summate such doses into lethal ones.
5. The insecticidal treatment may have cumulative effects through a reduction of mosquito breeding following destruction of the females of previous generations.
6. Considerable reduction in malaria transmission should gradually reduce the human malaria reservoir, so decreasing the risk of infection of the mosquito and increasing the hazards that it must survive before it can become infective.

It is fortunate that the reduction in the risk of malaria transmission bears a simple relation to the lethality of the insecticidal film, because the latter can be estimated by experiment. Two other important factors, the oöcyst and sporozoite infection rates within the mosquito population, will also vary with the effectiveness of the treatment, but the effects of the treatment on these indices, and of these indices upon the transmission risk, cannot be determined without an accurate knowledge of the age-structure of the normal mosquito population, a matter about which nothing is known in the case of *A. minimus* and little in relation to most other species. Hence the laborious determination of infection rates (which are statistically most indelicate indices) is not very likely to yield results of value when measuring the effectiveness of residual insecticide treatment. Similarly, lack of accurate knowledge of the age-structure of the population will foil any calculations of the relation between the anti-malarial effectiveness of the insecticide treatment and the reduction in the mosquito infestation as measured by biting risk or rate of entry.

Comparison of the Results of various Treatments with DDT and "Gammexane".

(a) *The Design of the Experiments.*

The main purpose of experiments with residual insecticidal films should be to determine their lethal effects upon the mosquito and, through these results, to estimate their possibilities in malaria control. Unfortunately it was not possible to design

experiments which were simple enough to be carried out on a large scale with the facilities available, and which would at the same time yield conclusive results, and the limitations that must be placed on the interpretation of the results now presented are realised.

A brief account of a preliminary experiment illustrates the type of difficulty involved. Five huts, with walls of bamboo and mud, and with thatched roofs, were specially built for an experiment. They were dark and very suitable for resting mosquitos, and were placed in a row, with gaps about 15 ft. wide between each hut. The central hut and the two end huts were treated with three different doses of DDT in kerosene whilst the other two were left untreated. White sheets were placed on the floors of all five huts and natives were paid to sleep in them. For several successive mornings the sheets were carefully eaxmined by Sgt. Hawkins, who was surprised to find that there were nearly as many dead mosquitos each morning on the floors of the untreated huts as on those of the treated ones. This experiment proved that numbers of mosquitos, having received lethal doses of insecticide, left the treated huts and entered other huts in which they died. It also provided a piquant illustration of the difficulties involved in this type of experiment, because complete results cannot be obtained without evidence to determine not merely the proportion of mosquitos that die within the treated huts, but the proportions that leave these huts before and after they have received a lethal dose of insecticide. This could only be determined by elaborate traps in which mosquitos leaving the hut could be held for a long interval, to determine the presence or absence of any delayed lethal effects—and these traps would be subject to considerable risk of contamination.

It was not possible to carry out a conclusive experiment of this nature on the scale considered desirable for the present experiments. The modified technique used had the advantage that it could be carried out on a large scale, and involved the use, without modification, of existing dwellings, but the recorded catches compare only the numbers of live mosquitos found in treated and untreated huts, and provide no evidence concerning the fate of those that might have been either killed or repelled, or excited to exit by a partially toxic dose. Their interpretation will be discussed later.

(*b*) *Insecticides used and Methods of Application.*

The insecticides used were "commercially pure" DDT (dichlordiphenyl-trichloroethane, para-para content c. 80 per cent.), and a sample of crude hexachlorocyclohexane containing 12 per cent. of the active gamma isomer, Gammexane. The DDT was used either in solution in Grade II kerosene or in an emulsion. The emulsion had been prepared by the Assam Oil Company Ltd. and in its undiluted form contained 22 per cent. DDT with the formula :—

DDT	220 grams.
Medium kerosene extract ...	586 ,,
Bar soap	39 ,,
Water	155 ,,

The hexachlorocyclohexane was used either in solution in medium kerosene extract, or in an emulsion similar to the DDT emulsion, but containing 7 per cent. of hexachlorocyclohexane in place of the DDT.

Both emulsions were miscible in any dilution with water. Medium kerosene extract is a cheap by-product of the refining of kerosene that according to the Assam Oil Company has a specific gravity of 0·917 at 60°F., initial and final boiling points at 181 and 279°C., and an aromatic content, as determined by loss to four volumes of 99 per cent. sulphuric acid, of 79·5 per cent. by volume. The very high aromatic content makes it a very efficient solvent for both DDT and Gammexane.

Treatments were applied by British personnel using calculated and measured doses of insecticide. The apparatus used was a stirrup pump, fitted with a spinner nozzle similar to that used on Knapsack oilers. The nozzle was held approximately 18 ins. from the treated surface, under which conditions about 75 per cent. of the dose would adhere to the surface and the rest would be wasted. The recorded doses are those used and not those which remained on the treated surfaces. In order to ensure fairly even coverage, all doses (with two stated exceptions) were applied at the rate of 1 quart of solution per 200 sq. ft. of treated surface, and variations in dosage were obtained by altering the concentration of the insecticides. The dose was so large that the whole treated surface was very thoroughly wetted by the application, but there was very little wastage due to run-off. It was usually found that when the whole room had been thoroughly treated the first time a small quantity of solution remained, and this excess was used immediately to re-cover the treated surface with an additional light application.

(c) *Method of Experiment.*

The experiments were conducted between March and December 1945 on Hilika Tea Estate, Doom Dooma, Upper Assam. This estate was infested with *A. minimus*, emanating from breeding areas in the Dibru River and its tributary streams and seepages ; the number, variety and inaccessibility of these breeding places had made economic larval control impossible.

The coolie lines had been placed in an irregular and scattered way over a length of several miles round the perimeter of the estate, alongside the banks of the Dibru River and its tributary the Hapjan River. The coolie huts varied in construction, but most of them had thatched roofs and mud walls. They were usually 20 ft. × 10 ft. in size, windowless and dark, and ventilated only by a gap at their eaves—as are most coolie huts everywhere. The maximum furniture was usually a charpoy bed and a few baskets and utensils.

Groups of three or four suitable huts were selected in the coolie lines and teams, each consisting of one B.O.R. and four coolies, sprayed these huts regularly and caught the mosquitos in them, using methods fully described elsewhere (Ribbands, 1946a). The catching schedule was arranged so that the mosquitos in each hut were caught every fourth day, and the groups to be treated were emptied on the same days as their untreated comparison groups.

Six pre-treatment catches were made in every hut. Groups of huts were then treated in various ways, each group receiving a different treatment, and an adjoining group always being left untreated as a comparison. The routine of catching in all huts every fourth day was continued uninterruptedly after the treatments, and their efficacy was judged by comparing the pre- and post-treatment ratios between treated groups and adjacent untreated groups. In all cases the results have been expressed by considering the actual post-treatment catch in the group of treated huts as a percentage of the catch which would have been obtained if the pre-treatment ratio had continued throughout the experiment.

All post-treatment catches in both treated and control huts were made in the afternoon, so that the insecticide had had at least eight hours in which to take effect. The recorded catches indicate only the presence or absence of mosquitos in the huts at this time.

The mosquitos involved in the experiment have been classified in three groups :—

(i) *A. minimus* group, comprising 60–80 per cent. *A. minimus*, Theo., with the balance mostly made up of *A. varuna*, Iyen., with a few *A. fluviatilis*, James, and *A. aconitus*, Dön.

(ii) *A. vagus* group, comprising 95 per cent. *A. vagus*, Dön., 5 per cent. *A. annularis*, Wulp, and occasional specimens of other species.

(iii) Culicines, comprising a considerable variety of species none of which were identified.

The results of the *A. minimus* group were intended as an index of the efficacy of the treatments for malaria prevention, and therefore only female mosquitos were considered in the compilation of these statistics. Both sexes of the other mosquitos were included. No significant differences in effects between sexes were noted.

(*d*) *Evaluation of the Results.*

The collected data are presented in Tables IV–X, which have been included so that the reader can at any stage refer to them in order to check the quantity of data from which the conclusions have been drawn. The results have been consolidated into periods of seven catches, so that each period covers an interval of four weeks. These statistics show separately the effects of the treatments on *A. minimus*, on the *A. vagus* group, and on the Culicines.

The results cannot be properly appreciated without some estimation of their probable margin of error, and the method used is not such that this margin can be deduced from a mathematical formula. An empirical estimate can, however, be made. Examination of Tables IV-VI, IX and X shows that when treatments became ineffective there were 32 instances in which the percentage of mosquitos remaining in the treated huts exceeded 100 per cent. of expectation. If it be assumed that by this time the effects of treatment had worn off, these 32 instances afford a guide to the margin of error involved in the technique used. In 12 instances the percentage remaining was between 100 and 150 per cent., in 13 instances between 150 and 200 per cent., in four instances between 200 and 300 per cent., and in three instances over 300 per cent. These figures indicate that the sampling error in the experiment (which could occur in either direction) was such that there was about one chance in eight that the real incidence of the mosquito infestation in a group of treated huts was more than twice the indicated incidence, and less than one chance in twenty that it was more than treble the indicated one.

The results have also been presented in diagrammatic form in figs. 1–4 and in compiling these only two criteria of efficiency have been used—reduction in infestation to either 10 per cent. or 30 per cent. of expectation. These results were based on moving averages over three consecutive catches. In the diagrams the duration of each portion of the experiment is indicated by the length of the box, the black portion of which represents the period when infestation was reduced by at least 90 per cent., the shaded portion the period when it was reduced by 70–90 per cent., and the white portion the period when the reduction, if any, was less than this. Where the indicated reduction is 90 per cent. there is less than one chance in twenty that the sampling error would have reduced this to less than 70 per cent. and, therefore, subject to the reservation already made concerning the design of the experiment, the black portions indicate complete malaria elimination. In the shaded portions, where a 70–90 per cent. reduction was indicated, malaria elimination would probably be complete.

There are instances where the results are incomplete because the mosquito infestation terminated before the treatments became ineffective; no results have been discarded.

(*e*) *Effects of complete Treatments with DDT.*

In this experiment the treatment was applied to cover all inside wall and roof surfaces, and any furniture present in the huts at the time of treatment. Seven groups of four huts were treated, and each group was compared with an adjacent untreated group of three huts. In each treated group three huts were treated with DDT in kerosene and the fourth with the same dose of DDT in emulsion. The seven different doses ranged from 5 per cent. DDT applied at the rate of 1 quart per 100 sq. ft. of surface to $\frac{5}{16}$ per cent. DDT applied at 1 quart per 200 sq. ft.

The consolidated results, before and after treatments, showing the effects of the treatments on all species, are presented in Tables IV and V. The results are also displayed as a diagram in fig. 1.

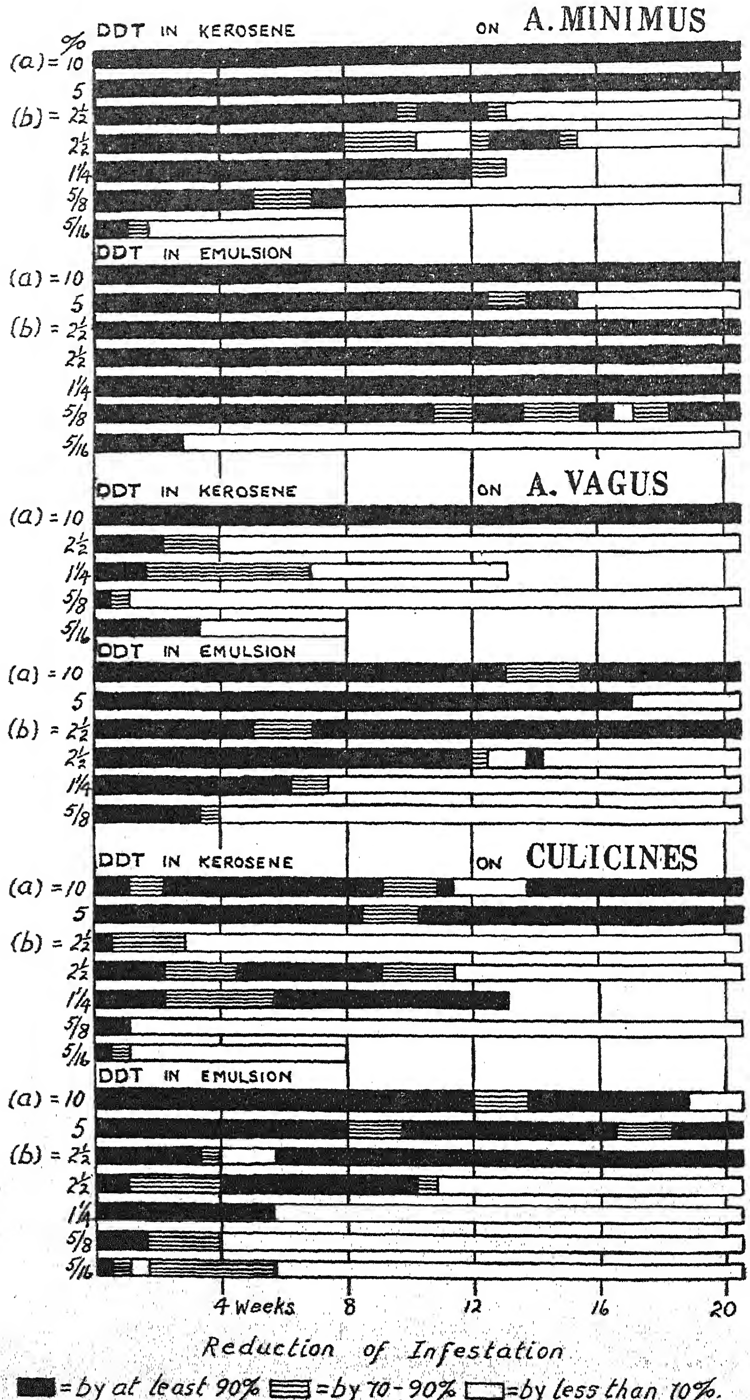

Fig. 1.—Results of complete interior treatments with DDT. (*a*) 5 per cent. at 1 quart per 100 sq. ft. (*b*) 5 per cent. at 1 quart per 400 sq. ft. All other doses at 1 quart per 200 sq. ft.

Treatment DDT 1 Kerosene		A. MINIMUS						A. VAGUS						CULICINES					
		Before DDT	Weeks after treatment					Before DDT	Weeks after treatment					Before DDT	Weeks after treatment				
			1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20
er cent., 1 uart/100 sq.	3 Untreated controls ...	124	95	222	47	37	53	71	58	127	38	60	14	196	94	179	71	17	4
	3 Treated huts	116	0	0	2	0	0	41	1	1	0	0	0	100	5	2	6	3	0
	PERCENTAGE REMAINING		0	0	5	0	0		3	1	0	0	0		10	2	17	35	0
er cent., 1 uart/200 sq.	3 Untreated controls ...	214	89	145	50	52	37							254	666	1863	694	60	21
	4 Treated huts	245	0	1	0	0	0							686	38	174	223	11	0
	PERCENTAGE REMAINING		0	1	0	0	0								2	4	12	7	0
er cent., 1 uart/400 sq.	3 Untreated controls ...	24	20	44	34	17	16	17	16	16	11	13	17	194	55	15	9	5	1
	3 Treated huts	106	0	7	11	26	38	11	3	17	5	34	21	351	20	32	26	12	12
	PERCENTAGE REMAINING		0	4	8	35	55		29	163	71	410	191		20	117	158	132	660
per cent., 1 uart/200 sq.	3 Untreated controls ...	275	61	58	40	38	26							83	109	133	98	16	7
	3 Treated huts	238	0	0	9	3	10							84	7	6	15	8	5
	PERCENTAGE REMAINING		0	0	26	9	44								7	5	15	50	71
per cent., 1 uart/200 sq.	5 Untreated controls ...	107	117	39	111			42	39	41	51			408	715	120	17		
	3 Treated huts	112	0	2	3			19	2	6	14			617	104	38	0		
	PERCENTAGE REMAINING		0	5	3				12	32	61				10	21	0		
er cent., 1 uart/200 sq.	3 Untreated controls ...	115	74	93	77	126	77	18	76	93	122	106	9	154	126	54	50	8	10
	3 Treated huts	182	6	16	71	54	41	9	22	61	102	57	13	180	38	30	30	11	20
	PERCENTAGE REMAINING		5	11	58	27	34		58	131	168	108	290		26	47	51	117	170
per cent., 1 uart/200 sq.	3 Untreated controls ...	123	26	43				28	23	40				176	44	41			
	3 Treated huts	66	3	45				9	0	21				170	13	29			
	PERCENTAGE REMAINING		22	195					0	163					31	73			

TABLE V.

Results after Complete Treatments with DDT in MKE Emulsion.

Treatment DDT in MKE Emulsion		A. MINIMUS Before DDT	A. MINIMUS Weeks after treatment 1–4	5–8	9–12	13–16	17–20	A. VAGUS Before DDT	A. VAGUS Weeks after treatment 1–4	5–8	9–12	13–16	17–20	CULICINES Before DDT	CULICINES Weeks after treatment 1–4	5–8	9–12	13–16	17–20
5 per cent., 1 quart/100 sq. ft.	3 Untreated controls ...	124	95	222	47	37	53	71	58	127	38	60	14	196	94	179	71	17	4
	1 Treated hut	49	0	0	0	1	0	20	0	0	0	2	0	69	0	0	1	1	1
	PERCENTAGE REMAINING		0	0	0	7	0		0	0	0	12	0		0	0	4	17	71
5 per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	111	38	39	22	15	16	9	33	39	88	12	10	841	227	62	40	8	5
	4 Treated huts	111	0	0	1	2	9	26	0	0	5	2	3	806	12	1	5	0	1
	PERCENTAGE REMAINING		0	0	5	13	56		0	0	20	6	10		6	2	13	0	21
per cent., 1 quart/400 sq. ft.	3 Untreated controls ...	24	20	44	34	17	16	17	16	16	11	13	17	194	55	15	9	5	1
	1 Treated hut	42	0	0	0	0	0	18	0	1	0	0	0	386	5	5	1	0	0
	PERCENTAGE REMAINING		0	0	0	0	0		0	6	0	0	0		5	17	6	0	0
per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	275	61	58	40	38	26	36	120	137	125	32	9	83	109	133	98	16	7
	1 Treated hut	144	0	0	0	1	1	5	0	2	0	5	0	44	7	1	3	6	0
	PERCENTAGE REMAINING		0	0	0	5	7		0	11	0	112	0		12	2	6	70	0
per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	420	111	53	47	86	53		72	53	68	48	7	597	99	36	32	19	13
	1 Treated hut	40	0	0	0	1	0		0	2	15	3	4	86	0	1	2	2	1
	PERCENTAGE REMAINING		0	0	0	12	0		0	30	172	100			0	20	44	73	54
per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	115	74	93	77	126	77	18	76	93	122	106	9	154	126	54	50	8	10
	1 Treated hut	128	0	2	5	13	19	6	1	19	49	31	5	123	7	32	23	9	16
	PERCENTAGE REMAINING		0	2	6	10	22		4	61	120	88	167		7	74	58	140	200
per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	123	26	43	51	42	22												
	1 Treated hut	28	1	4	9	5	6												
	PERCENTAGE REMAINING		17	40	78	52	120												

The following conclusions are drawn from the results :—

(i) DDT emulsion was considerably more effective than the same quantity of DDT in kerosene solution—against *A. minimus* $1\frac{1}{4}$ per cent. emulsion was effective for 20 weeks, but 5 per cent. solution was required for an equal effect, and in lesser doses the emulsion remained effective more than twice as long as the solution ; against *A. vagus* the emulsions were effective for at least four times as long as the solutions ; more contradictory results were obtained against Culicines, but the emulsions were generally better.

(ii) The same treatment with DDT usually remained effective against *A. minimus* for about twice as long as against either *A. vagus* or Culicines.

(iii) The duration of effectiveness was very markedly increased by increase of dosage. Doubling of the smaller doses usually approximately doubled the duration of effectiveness, but the larger doses were effective for so long that it was not possible to determine whether this principle continued to hold good. These results prove that heavy doses at infrequent intervals are more economical than frequently repeated light doses.

(iv) The following doses of DDT, applied at the rate of 1 quart/200 sq. ft., were effective for 20 weeks : 5 per cent. DDT in solution, against *A. minimus* and Culicines ; $1\frac{1}{4}$ per cent. DDT in emulsion, against *A. minimus* only ; 5 per cent. DDT in emulsion, against Culicines. The following doses were effective for 10 weeks : $1\frac{1}{4}$ per cent. DDT in solution, against *A. minimus* ; $\frac{5}{8}$ per cent. DDT in emulsion, against *A. minimus* only ; $2\frac{1}{2}$ per cent. DDT in emulsion, against *A. vagus* and Culicines.

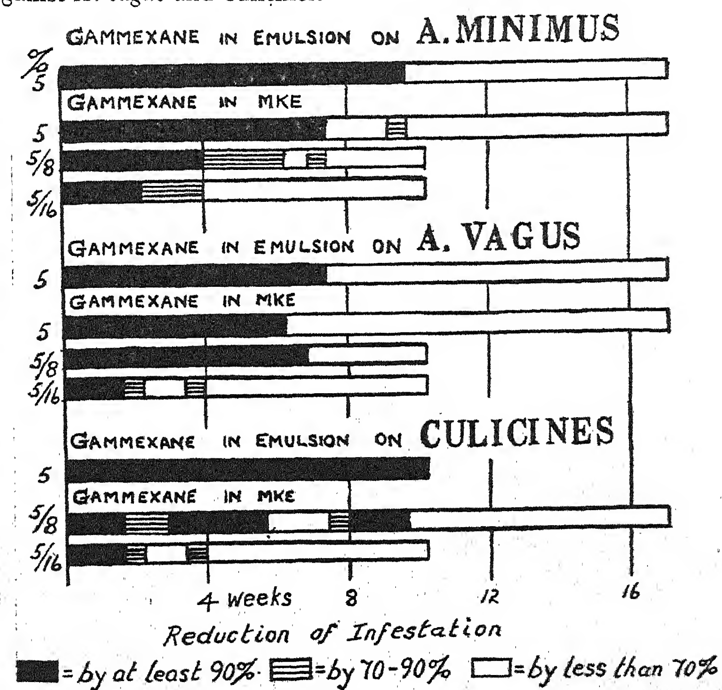

Fig. 2.—Results of complete interior treatments with Gammexane.

(*f*) *Effects of complete Treatments with Gammexane.*

A smaller series of experiments was made with Gammexane, using the same methods as in the experiments with DDT, but with only three different doses—$\frac{5}{16}$ per cent., $\frac{5}{8}$ per cent. and 5 per cent. hexachlorocyclohexane applied at the rate of 1 quart per 200 sq. ft. of surface. Treatments were in solution, but the 5 per cent. dose was also applied in emulsion.

TABLE VI.

Results after Complete Treatment with Gammexane.

Hexachlorocyclohexane Treatment		A. minimus					A. vagus					Culicines				
		Before Dose	Weeks after dose				Before Dose	Weeks after dose				Before Dose	Weeks after Dose			
			1–4	5–8	9–12	13–16		1–4	5–8	9–12	13–16		1–4	5–8	9–12	13–16
Emulsion: 5 per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	151	27	18	27	6	13	10	14	21	7	572	144	28		
	1 Treated hut	28	0	0	2	3	3	0	0	4	1	123	0	0		
	Percentage Remaining		0	0	40	270		0	0	82	61		0	0		
Solution: 5 per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	151	27	18	27	6	13	10	14	21	7	572	144	28	18	0
	3 Treated huts	71	0	0	9	11	10	0	1	12	4	443	5	3	7	2
	Percentage Remaining		0	0	70	380		0	9	74	74		5	14	51	∞
Solution: $\frac{5}{8}$ per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	128	280	229	(10)		85	92	25	(4)						
	2 Treated huts	52	2	21	(8)		86	2	2	(1)						
	Percentage Remaining		2	23	197			2	8	25						
Solution: $\frac{5}{16}$ per cent., 1 quart/200 sq. ft.	3 Untreated controls ...	102	64	54			49	65	40			73	23	29		
	3 Treated huts	85	3	36			31	5	16			51	3	15		
	Percentage Remaining		6	80				12	64				19	74		

The results are presented in Table VI and fig. 2 and from them the following conclusions are drawn, which indicate the differences between the effects of Gammexane and DDT :—

(i) The duration of effectiveness of hexachlorocyclohexane against *A. vagus* and Culicines was not markedly different from the duration of effectiveness against *A. minimus*.

(ii) The single emulsion experiment indicated that at the 5 per cent. dosage the hexachlorocyclohexane emulsion was effective for only slightly longer than the solution.

(iii) Five-eighths per cent. hexachlorocyclohexane solution was effective for nearly twice as long as the $\frac{5}{16}$ per cent. solution, but increase of dose from $\frac{5}{8}$ per cent. to 5 per cent. increased the duration of effectiveness only slightly. Although the $\frac{5}{8}$ per cent. solution seems effective for nearly 8 weeks, yet 5 per cent. was effective for only 8–10 weeks, and it is therefore unlikely that mere increase of dosage will markedly increase the duration of effectiveness, and likely that treatments with Gammexane will have to be repeated at more frequent intervals than treatments with DDT.

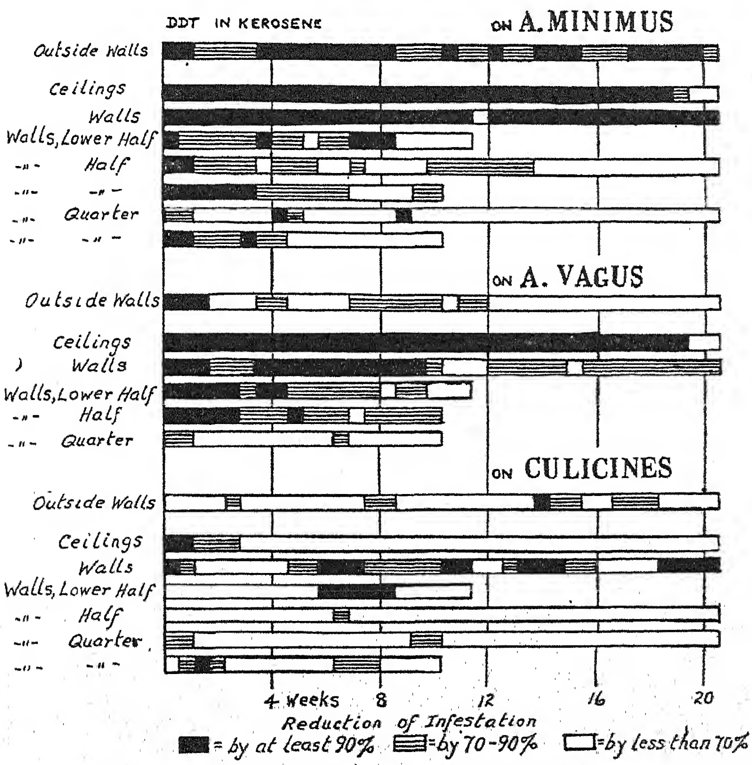

Fig. 3.—Results of partial treatments with DDT.

(g) *Effects of partial Treatments with DDT.*

Calculations having shown that complete malaria elimination should be obtainable by the use of treatments which were only partially lethal, a third series of experiments was commenced in order to determine whether effective reductions in mosquito infestation could be obtained by treatments of portions of dwellings. All treatments were made with 5 per cent. DDT in kerosene, applied at the rate of 1 quart per 200 sq. ft. of surface.

TABLE VII.

Results after Partial Treatments with DDT in Kerosene.

Treatment (5 per cent. DDT, 1 qt/200 sq. ft.)		A. minimus						A. vagus						Culicines					
		Before DDT	Weeks after treatment					Before DDT	Weeks after treatment					Before DDT	Weeks after treatment				
			1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20
Ceilings	3 Untreated controls ...	275	134	77	71	66	38	17	30	36	37	25	11	76	90	84	55	20	17
	4 Treated huts	335	1	1	1	2	2	30	2	4	3	1	1	85	23	46	34	22	12
	Percentage Remaining		1	1	1	3	4		4	6	5	2	5		22	49	55	98	63
Walls	3 Untreated controls ...	74	34	31	85	43	41	13	36	29	51	31	11	945	184	52	42	12	14
	4 Treated huts	201	1	0	4	10	5	26	5	4	19	15	3	1002	48	8	8	2	3
	Percentage Remaining		1	0	2	9	5		7	7	19	24	14		24	14	18	15	20
Half of Walls ...	3 Untreated controls ...	134	28	21	69	55	35							46	27	31	27	12	8
	4 Treated huts	292	9	14	43	57	47							106	33	39	40	20	8
	Percentage Remaining		13	31	29	47	62								53	54	63	72	43
Half of Walls ...	3 Untreated controls ...	128	280	259	(10)			85	92	25									
	3 Treated huts	161	10	77	(8)			123	7	4									
	Percentage Remaining		3	21	63				5	11									

TABLE VIII.

Results after Partial Treatments with DDT in Kerosene.

Treatment (5 per cent. DDT, 1 qt/200 sq. ft.)		A. MINIMUS						A. VAGUS						CULICINES					
		Before DDT	Weeks after treatment					Before DDT	Weeks after treatment					Before DDT	Weeks after treatment				
			1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20		1–4	5–8	9–12	13–16	17–20
Lower Halves of All Walls	3 Untreated controls ...	420	34	103	37			41	57	49	5			36	21	29	4		
	3 Treated huts	185	2	8	9			124	9	21	5			36	14	4	6		
	PERCENTAGE REMAINING		13	18	55				5	14	33				66	14	150		
Quarter of Walls ...	3 Untreated controls ...	107	24	12	13			7	11	8	4			437	62	42	21		
	4 Treated huts	119	12	5	14			3	6	12	3			623	39	39	13		
	PERCENTAGE REMAINING		45	38	97				127	350	175				44	65	43		
Quarter of Walls ...	3 Untreated controls ...	102	64	54	(1)			49	65	40				73	23	29			
	3 Treated huts	115	7	21	(4)			20	15	18				49	6	6			
	PERCENTAGE REMAINING		10	35	350				56	110					39	31			
Band Round Eaves	3 Untreated controls ...	139	53	28	37	24	27							36	32	24	17	15	35
	4 Treated huts	271	1	3	19	29	13							125	17	33	47	26	6
	PERCENTAGE REMAINING		1	6	26	60	24								16	38	80	50	5
Outside Walls and Eaves	3 Untreated controls ...	66	29	56	117	245	119	11	50	96	235	216	16	70	56	28	68	18	30
	4 Treated huts	244	9	17	45	81	32	7	15	29	36	52	7	90	28	21	31	7	11
	PERCENTAGE REMAINING		9	8	10	9	7		47	47	24	38	69		39	59	36	30	29

Treatments were given to the external walls of dwellings, to ceilings or their equivalent, and to inside walls and portions of walls. The results are presented in Tables VII and VIII and fig. 3, and from them the following conclusions are drawn :—

(i) *Treatment of exterior walls and eaves only.*

This treatment apparently reduced infestation by Culicines and *A. vagus* by one-half, but such a reduction is not necessarily significant. *A. minimus* infestation was reduced by more than 90 per cent., and this reduction was maintained for 20 weeks.

The duration of this external treatment throughout the rainy season is associated with the fact that these native huts have wide overhanging eaves, and the treatments were presumably effective in the vicinity of the eaves, which are the point of mosquito entry. The big reduction in *A. minimus* infestation tends to confirm a supposition that females frequently rest on the outside of huts before they enter to feed.

(ii) *Treatment of ceilings or insides of roofs only.*

This treatment reduced infestation of both *A. minimus* and *A. vagus* by more than 95 per cent. for 19 weeks, but had only a very temporary effect on Culicines.

These results indicate the likelihood that treatment of ceilings and the insides of roofs will be quite sufficient for control of *minimus*-induced malaria, and it will be unnecessary to apply the treatments to the walls also.

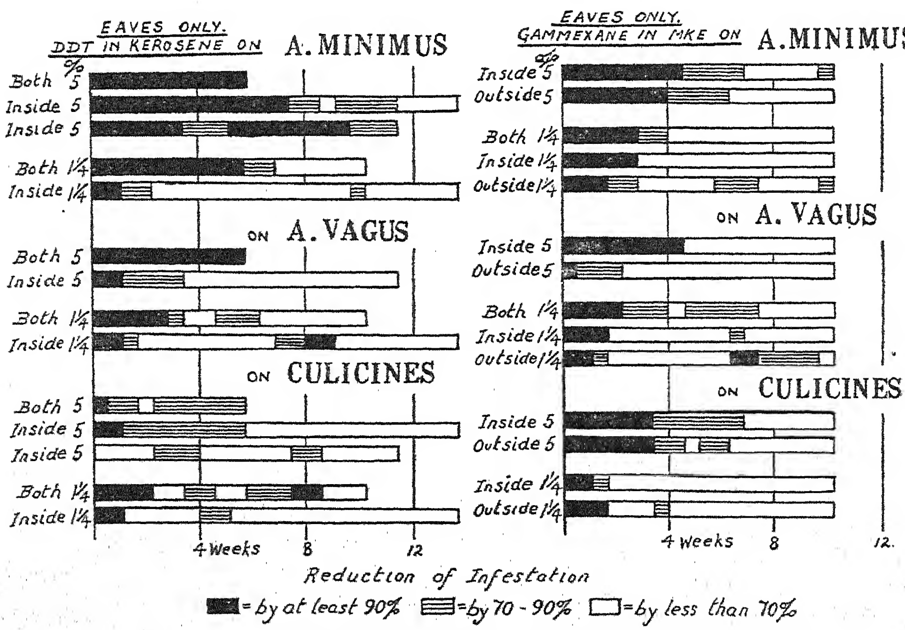

Fig. 4.—Results of treatments of eaves only with DDT or Gammexane.

(iii) *Treatment of inside wall surfaces only.*

This treatment was more than 90 per cent. effective against *A. minimus* for 20 weeks, but was not quite so effective against *A. vagus*. Culicines showed approximately an 80 per cent. reduction. This result indicates that treatment of walls only, without treatment of ceilings, will be quite sufficient for control of *A. minimus*.

(iv) *Treatment of the lower halves of walls only.*

This treatment substantially reduced Anopheline infestation for eight weeks, but had less effect on Culicines.

(v) *Treatments of one-half and one-quarter of the wall surface only.*

In these experiments each wall was divided vertically into two or four panels and the treatment applied to one panel of each wall. Such very partial applications would be expected to yield very irregular results, but they demonstrate marked reductions in *A. minimus* infestation in all cases and indicate a lesser reduction in the Culicine infestation.

In these experiments the effect of the treatment wore off rapidly; it was markedly less in each succeeding month and no significant reductions were noticeable after the end of the second month.

(*h*) *Effects of Treatments of eaves only with DDT and ' Gammexane '.*

Coolie huts, which are windowless, are open at their eaves, and this gap must be the usual means of entry and exit for mosquitos. Treatments of eaves only were therefore made. The spray was applied either from outside the hut, or inside, or both sides; in all cases the object was to apply a band of insecticide so that it covered the gap, and the wall and roof on either side of it, for a width of about 9 inches. 5 or $1\frac{1}{4}$ per cent. solutions of DDT or hexachlorocyclohexane were used and they were applied at the rate of 1 quart per 200 sq. ft. of surface.

The results are presented in Tables IX and X and fig. 4 and lead to the following conclusions:—

(i) The DDT treatments were considerably more effective against *A. minimus* than against *A. vagus*, and rather more effective against the latter than against Culicines, but the effects of the Gammexane treatments were not very different for different species—this confirms the conclusion drawn from the results of complete treatments with both chemicals.

(ii) Bands of $1\frac{1}{4}$ per cent. solutions are of no practical value, because their effects wear off too quickly. At this strength Gammexane treatments were usually more persistent than those with DDT.

(iii) In both cases the 5 per cent. treatments were more durable than the equivalent $1\frac{1}{4}$ per cent. treatments, but, as in the results of complete treatments, the effect of increased dosage was relatively much greater in the case of DDT.

(iv) With Gammexane internal and external treatments were equally effective, and treatment both inside and outside was slightly more effective than either single treatment. No external treatments with DDT were made, but treatment both inside and outside was considerably more effective than inside treatment only—this difference might be expected to follow as a corollary of the previous conclusion, since treating both surfaces doubles the quantity of insecticide required.

(v) Bands of 5 per cent. DDT were more than 90 per cent. effective against *A. minimus* for eight weeks and 70 per cent. effective for 12 weeks, but they wore off after this period. As the effectiveness of complete treatments with DDT persisted for at least 20 weeks it is likely that bands containing heavier concentrations of DDT would remain effective for this period also. Bands of 5 per cent. hexachlorocyclohexane were 90 per cent. effective for about four weeks against all species and 70 per cent. effective for seven weeks, and comparison with the results of complete treatments indicates that, with increased dosage, the effective period might have been extended to ten weeks.

TABLE IX.

Results after Treatments of Eaves with Bands of DDT.

Treatment (1 qt./200 sq. ft.) DDT in Kerosene		A. MINIMUS Before Dose	A. MINIMUS Weeks after dose 1–4	A. MINIMUS Weeks after dose 5–8	A. MINIMUS Weeks after dose 9–12	A. VAGUS Before Dose	A. VAGUS Weeks after dose 1–4	A. VAGUS Weeks after dose 5–8	A. VAGUS Weeks after dose 9–12	CULICINES Before Dose	CULICINES Weeks after dose 1–4	CULICINES Weeks after dose 5–8	CULICINES Weeks after dose 9–12
5 per cent. solution :	3 Untreated controls ...	56	111	(25)		85	23	(2)		145	9	(4)	
Inside and Outside	4 Treated huts	54	1	(0)		128	0	(0)		319	3	(2)	
	PERCENTAGE REMAINING		1	0			0	0			15	23	
5 per cent. solution :	3 Untreated controls ...	139	53	28	37					36	32	24	17
Inside only	4 Treated huts	271	1	3	19					125	17	33	46
	PERCENTAGE REMAINING		1	6	26						16	38	80
5 per cent. solution :	3 Untreated controls ...	47	42	44	18	25	30	29	5	27	18	17	2
Inside only	3 Treated huts	41	0	4	2	20	3	16	2	26	8	9	5
	PERCENTAGE REMAINING		0	10	13		13	69	50		46	55	260
1¼ per cent. solution :	3 Untreated controls ...	102	64	54		49	65	40		73	23	29	
Inside and Outside	3 Treated huts	111	1	13		13	1	6		99	4	7	
	PERCENTAGE REMAINING		1	22			6	56			13	18	
1¼ per cent. solution :	3 Untreated controls ...	56	66	470	111	83	108	58	23	145	42	21	9
Inside only	3 Treated huts	48	15	178	38	135	29	25	1	166	23	10	17
	PERCENTAGE REMAINING		26	44	40		17	27	3		48	41	164

TABLE X.

Results after Treatments of Eaves with Bands of Gammexane.

Treatment (1 qt./200 sq. ft.) Hexachlorocyclohexane in MKE		A. minimus				A. vagus				Culicines			
		Before Dose	Weeks after dose			Before Dose	Weeks after dose			Before Dose	Weeks after dose		
			1–4	5–8	9–12		1–4	5–8	9–12		1–4	5–8	9–12
5 per cent. solution :	5 Untreated controls ...	107	117	139	111	42	39	41	51	408	715	120	17
Inside only	3 Treated huts	138	0	17	37	22	0	33	22	375	32	26	15
	Percentage Remaining		0	10	26		0	154	82		5	24	96
5 per cent. solution :	5 Untreated controls ...	107	117	139	11	42	39	41	51	408	715	120	17
Outside only	3 Treated huts	259	10	36	127	71	40	59	96	497	47	45	30
	Percentage Remaining		4	11	48		73	85	112		6	31	145
1½ per cent. solution :	3 Untreated controls ...	128	280	229		85	92	25					
Inside and Outside	3 Treated huts	58	10	83		95	12	5					
	Percentage Remaining		8	80			12	18					
1½ per cent. solution :	3 Untreated controls ...	46	4	83	23	23	20	28	5	64	15	12	8
Inside only	3 Treated huts	50	4	88	23	34	10	28	3	125	7	15	18
	Percentage Remaining		92	98	92		34	68	41		24	64	115
1½ per cent. solution :	3 Untreated controls ...	56	66	470	111	85	108	58	23	145	42	21	9
Outside only	3 Treated huts	32	12	84	43	62	16	14	4	57	6	7	9
	Percentage Remaining		32	31	68		20	33	24		36	85	254

(*i*) *Differences between Solutions and Emulsions.*

The marked superiority of the DDT emulsions over the DDT solutions was most interesting. It might have been a consequence of crystallisation into different sizes of crystals, with different properties, from the strong and the weak solutions (*cf.* Barnes, 1945), but perhaps a more likely explanation is that in solution a large proportion was absorbed into the sprayed surface, while in emulsion the water was more readily absorbed and the oil-bound DDT remained as a film on the top of the wetted surface. The action of the emulsion would then be similar to the probable action of certain adhesive agents which Barnes (1946) has shown can effect considerable economies in DDT, and which she suggests act by blocking the minute pores of the treated surface and minimising the absorption of the DDT solution.

(*j*) *Differences between DDT and Gammexane.*

Two important differences between DDT and Gammexane were revealed by these experiments :—

(1) Increasing the dose of DDT, or applying it in emulsion form, markedly increased the duration of its effectiveness, but these measures had much less effect in the case of ' Gammexane '.

(2) The duration of the effectiveness of DDT varied considerably with different species, while that of the Gammexane showed little variation between species.

It is thought that both differences arise because the vapour pressure of DDT is considerably lower than that of Gammexane. The latter is therefore less persistent and it is much more difficult to increase its persistence by increasing the dose. The similarity in the effects of Gammexane for different species could be caused by rapid evaporation of the thin film so that, when its strength was below the threshold for affecting the more resistant Culicines, the film quickly deteriorated and became ineffective against the less resistant *A. minimus.*

(*k*) *The Mode of Action of the Insecticidal Films.*

The mode of action of the two insecticides embraces other possible differences between them. The results of these experiments indicate only the proportion of mosquitos that were alive in the treated huts on the afternoons when the catches were made, expressed as a percentage of the number that would have been expected in them if they had not been treated. The mosquitos missing from the huts may or may not have been killed.

If they were not killed they may either have been repelled, so that they did not enter the huts at all, or they may have been so excited by absorption of a partially toxic dose that they escaped from the huts before absorbing a lethal dose.

The possibility that a large proportion of the mosquitos might be repelled from entry has already been demonstrated ; single flittings of native huts with small quantities of pyrethrum in kerosene can deter a very high proportion of *A. minimus* from entry for several days (Ribbands, 1946c) and, as the doses used in the present series of experiments were about 100 times as great as those used in the repellency tests, it is unfortunate that it was not possible to measure the repellent effect, if any, of the DDT and Gammexane treatments now used. No detailed experiments made to determine the importance of this factor are known to the writer, but published opinions are that DDT/kerosene solutions produce no distant repellent effect either on mosquitos (*e.g.* Lindquist & McDuffie, 1945) or on flies (*e.g.* Blakeslee, 1944), and it is therefore quite likely that Gammexane can exert a distant repellent effect. Dr. J. S. Kennedy (1946), working at Porton, found that Gammexane vapour had a rapid excitatory action on mosquitos, while DDT had no effects under similar experimental conditions.

Gahan and others (1945) have recorded that many mosquitos escape from DDT treated rooms but stated that 95 per cent. of them, when trapped, died within 24 hours. Kennedy, in further work at Porton, showed that mosquitos which rest on DDT treated surfaces quickly became excited and left ; this frequently occurred before they had absorbed a lethal dose, and such mosquitos subsequently recovered ; these results have been confirmed by Hadjinicolaou, working at the London School of Tropical Medicine.

These effects of partial toxicity, and of repellency, show that the absence of mosquito infestation cannot at present be used as a criterion of the lethality of residual film treatment, either with DDT or Gammexane, and that the present series of experiments, like the results of many other field trials, should not be interpreted as evidence that the various treatments are necessarily effective for as long as the results indicate. The value of the present results lies primarily in the indications that they provide for the relative persistence of many different types of treatments, and in the fact that they indicate maximum periods beyond which treatments cannot be effective.

Their potential value would be altered, but not necessarily reduced, if further laboratory and field experiments should confirm that excitation and subsequent repellency plays an important part in the mode of action of either type of film. Excitatory effects would be most important under tropical conditions, because excited insects would probably tend to fly towards the light and there would be no windows to impede their exit. In such circumstances, in the case of DDT where no distant repellent effect is involved, the aim of treatment should be to ensure, if possible, that the treated surfaces are covered by a dose so heavy that a single alighting will cause the mosquitos to acquire a lethal dose before they have become excited. This aim can possibly be most easily accomplished if very heavy doses are applied to restricted areas, and this fact may invest the method of partial treatment with a new and greater importance. Treatment of eaves and openings would have the additional advantage that excited mosquitos would tend to touch these surfaces during their attempts to leave.

(*l*) *The Resting Habits of the Mosquitos.*

Subject to the supposition that the DDT treatments produced no distant repellent effects, their results can be interpreted to yield information concerning the behaviour of the mosquitos within the treated huts. Treatments of only one-half of the walls reduced infestation of *A. minimus* by an average of 82 per cent. for two months and treatments of only one-quarter of the walls reduced this infestation by 68 per cent. for this period ; these results indicate that the individual mosquito usually touches or alights more than once on the wall surface ; the latter result, although it seems high, would be accounted for by an average of four random touches per insect, and the former by only three. The reductions in the *A. vagus* and the Culicine infestation after these treatments were much less marked, but since these mosquitos come in for shelter only whereas the *A. minimus* group come in to feed, and to rest before feeding, this difference seems reasonable.

The results of the application of bands of insecticide to the eaves indicate that a very high proportion of *A. minimus*, and a considerable proportion of the other mosquitos, touch or alight on this surface as they enter the huts.

The effects of the partial treatments, involving either the eaves or portions of the wall surfaces, all wore off fairly rapidly and were effective for a much shorter period than the treatments of complete huts. This indicates that the DDT film gradually loses its effect, so that at first short contacts affect the insect but later it is only affected after several, or longer, contacts.

The successful result of the treatment of the exterior wall surfaces indicates that about 90 per cent. of *A. minimus* touched these surfaces before entry ; in this case the effect persisted as long as the effects of the complete treatments, and so provides circumstantial evidence that the incoming mosquitos usually rested on or walked over the outside walls and did not merely touch the surface in passing through the eaves.

Almost complete reductions in the *A. minimus* infestation after treatment of ceilings only, and the long persistence of this effect, indicates that *A. minimus* nearly always spent a portion of its sojourn on the ceiling. This result conforms with the observation of Thomson (1941) that *A. minimus* preferred to rest under horizontal in the lower half of the room. Treatments of the lower halves of walls only, in the surfaces, but Thomson stated that the great majority of those found by him were present experiments, were much less effective than treatments of ceilings.

The results indicate that ceilings were also attractive to *A. vagus*, but not to Culicines ; for the latter, ceiling treatments were less effective than treatments of eaves only, so their effects were probably exerted only at the eaves.

(m) Practical Applications of the Results.

Comparison of emulsions with kerosene solutions showed that the former were very superior as vehicles for DDT and at least as good for Gammexane. Emulsion concentrates should also cost less and reduce transport charges, and they are less susceptible to petty pilfering. Therefore they will probably displace kerosene solutions as vehicles for the application of residual films. Considerable work may be required in order to decide the most economical form of emulsion concentrate.

The results indicate that mosquito control might be accomplished by partial treatments of room surfaces and that, against *A. minimus*, treatments of either roofs or walls would be sufficient and treatment of both unnecessary. Of these two alternatives, treatments of roofs and ceilings would normally be preferred, because they cover a smaller surface area and therefore require less material, and also because such treatments are not likely to be disturbed by the occupants of the huts, who occasionally clean or replaster the walls. Where ceilings are very high their treatment is difficult and wall treatments are then more convenient.

Because the results may be partly attributable to repellent or temporary toxic effects they would be mainly valuable as a guide in the framing of conclusive large-scale field experiments, in which those treatments, indicated by the present tests as likely to succeed, could be the subject of more elaborate entomological tests or could be applied on a community-wide scale so that their effects on the reduction of malaria incidence could be determined. Properly organised treatments of whole communities would have the advantage over entomological tests, in that they would provide convincing demonstrations of the extent to which these new methods can reduce malaria incidence under practical conditions. The following treatments seem worthy of exhaustive trial on this basis, in emulsion vehicles and at doses of 1 quart per 200 sq. ft. of surface : (1) 5 per cent. DDT, complete treatment, (2) 5 per cent. DDT, ceilings only, (3) 5 per cent. DDT, walls only, (4) 5 per cent. hexachlorocyclohexane, complete treatment, (5) 5 per cent. hexachlorocyclohexane, ceilings only, (6) 5 per cent. hexachlorocyclohexane, walls only. The first three may be effective for more than 20 weeks and the last three for 8–10 weeks.

The applications of bands of insecticide to eaves gave encouraging results and there was a clear indication that, with heavier doses, the duration of effectiveness might have been considerably extended. Further trials should be conducted with 5 per cent. and 10 per cent. hexachlorocyclohexane, on both external and internal eaves, and with 5 per cent., 10 per cent. and 20 per cent. DDT, also with both types of treatment ; it is possible that some of these treatments might prove as durable as, and more economical than, treatments of ceilings or walls.

Should experiments show that Gammexane exerts any considerable distant repellent effect, its function in malaria prevention may differ from that of DDT. Unless Gammexane can be incorporated in a vehicle that will increase its persistence the greater durability of DDT films may give them advantages for use against house-haunting vectors, such as *A. minimus*. On the other hand, experiment might possibly demonstrate that the repellent properties of Gammexane are so considerable that it can be used on dwellings in order to keep out vectors such as *A. maculatus*, which might otherwise enter to bite and yet not remain long enough to absorb a lethal dose of DDT ; by this means also anthropophilic feeding habits might be changed to zoophilic ones, with consequent malaria elimination. Such a repellent effect might also be used in individual dwellings to protect susceptible individuals who may be temporarily stationed amongst an infected and semi-immune community. Further work will show to what extent these two insecticides will be competitors, and to what extent they will be complementary, in programmes for malaria control.

Summary.

(1) Sprays that are atomised and mingled with air were unsuitable because they were wasteful in both material and labour.

(2) Knapsack oilers and modified stirrup pumps were efficient. Where labour is cheap hand-operated sprayers of this type are more economical than motor-operated machines.

(3) The relation between mosquito mortality and infectivity is discussed and it is calculated that any treatment which produces 75 per cent. mortality among the mosquitos exposed to it should effect malaria elimination.

(4) The effects of a DDT emulsion were much more durable than those of a similar quantity of DDT in kerosene solution. The difference was much less marked when Gammexane was used. Emulsions will probably displace kerosene solutions as vehicles for the application of residual films.

(5) The persistence of the effects of DDT was markedly increased by increased dosage, so that it will be most economical to apply DDT in heavy doses at long intervals.

(6) The persistence of Gammexane effects was not greatly increased by increased dosage because it evaporates much more quickly than DDT. It is not likely to be effective for much longer than 10 weeks.

(7) Treatments with DDT were usually effective against *A. minimus* for about twice as long as against *A. vagus* or Culicines, but treatments with Gammexane had similar effects on all species.

(8) Extensive reductions in mosquito infestation were produced by various treatments with DDT and Gammexane. It is considered that these were partly attributable to repellent and temporary toxic effects, and further work is necessary to determine the duration of the lethal effects. The reductions obtained indicated that :—

(*a*) Treatments of either ceilings or walls only of dwellings reduced *A. minimus* infestation by 95 per cent., and treatment of both surfaces may be unnecessary.

(*b*) Temporary reduction in infestation by *A. minimus* was secured by applying bands of insecticide to the eaves of dwellings only (either inside or outside). Experiments with heavier concentrations of insecticide may prove this to be the most economical method of treatment.

(*c*) 90 per cent. reduction in *A. minimus* infestation was secured by treatment of exterior walls of dwellings only.

(9) Now that excitant and temporarily toxic effects of DDT films have been demonstrated (Kennedy, 1946) the aim of treatments should be to ensure if possible, that treated surfaces are covered by a dose so heavy that a single alighting will cause a slight lethal dose to be acquired by the mosquitos before they become excited. This aim is most likely to be accomplished by applying very heavy doses to restricted areas, in accordance with the methods of partial treatment now described.

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THE EXCITANT AND REPELLENT EFFECTS ON MOSQUITOS OF SUB-LETHAL CONTACTS WITH DDT.

By J. S. Kennedy, Ph.D.

Introduction.

During the war it was necessary to concentrate on the practical development of DDT as an insecticide without waiting for studies of its mode of action. Working assumptions had to be made, especially with regard to the possible repellency of DDT deposits. Buxton (1945) sums up what has been the accepted opinion on this subject, as follows: "DDT does not act as a repellent to any insect, so far as is known." The time has come to examine this conclusion more closely. There is plenty of evidence that any repellency it has is not enough to deprive DDT of its outstanding effectiveness as a "residual" insecticide. There is no evidence that DDT has any distant repellent action. But the existence of contact repellency has been firmly established. Buxton (1945) mentions "restlessness" as an early symptom of DDT poisoning. This has been described under semi-field conditions by Gahan and others (1945) and by Metcalf and others (1945), who observed also that mosquitos excited by contact with DDT no longer stayed in dark corners but made for the windows. However, such repellency has been discounted as of no practical significance because, in Buxton's (1945) words: "So far as is known, once visible symptoms develop, death follows: recovery from an early stage of poisoning does not occur." This idea is perhaps even more widespread than the idea that DDT is not repellent, as may be instanced by the emphatic way in which a German writer, Rose (1944), expresses it: "At the first appearance of excitation as a symptom of poisoning, it is already too late for the mosquito. Its fate is sealed."* Our laboratory observations did not bear out these statements.

The symptoms displayed by *Aëdes aegypti*, L., after tarsal contact with DDT deposits, have been observed on a large number of occasions in this laboratory. These observations will be reported elsewhere (Toms & Callaway, in preparation) but may be summarised as follows. The symptoms are, in order of appearance: excitation, ataxia, convulsions, general paralysis ("knock-down") and, ultimately, death. The symptoms displayed by *Anopheles maculipennis atroparvus*, van Thiel, are much the same except that autotomy of the legs is common during ataxia and convulsions. In both species the excitation appears quickly, often in a matter of seconds after the insects are brought into contact with DDT, and before there is any loss of co-ordination. Excitation continues as the later symptoms develop although increasingly interfered with by them. It has been observed repeatedly that mosquitos may show all the symptoms up to and including knock-down during the minutes or hours following contact with DDT, and even during contact in the case of long exposures to low deposit densities, and yet recover by 24 hours and live in apparent health for a further 48 hours at least. Thus the appearance of all the characteristic DDT symptoms short of death is no sure indication that the affected mosquitos are going to die. These findings led to the present work on DDT repellency.

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* "Wenn sich als Zeichen der Vergiftung die ersten Erregungserscheinungen zeigen, ist es für die Mücke bereits zu spät. Ihr Schicksal ist besiegelt".

Experiments.

1. *DDT-treated and untreated surfaces exposed separately.*

All experiments were done in a room maintained at 28°C. and 60–70 per cent. relative humidity. The insects were observed in a glass box 10 cm. high and 8 cm. square in section, diffusely but fairly brightly lit from above and slightly in front. The glass box was placed inside a larger opaque box with a narrow front opening. The observer sat in a dimmer light looking through a white mosquito netting curtain so as not to disturb the insects. The back wall of the glass box was lined with white No. 1 Whatman filter paper. The mosquitos showed a marked preference for resting on the paper rather than the glass. The paper was dipped either in acetone alone or in a 2 per cent. w/v solution of pure DDT in acetone, drained in saturated acetone vapour, dried thoroughly and weighed before use. The DDT density was about 2 g./m.^{2} (about 200 mg./ft.^{2}) of paper.

For each test 10, sugar-fed, 1–3-day-old, female mosquitos were withdrawn from a storage cage with a sucking tube and blown gently into the glass box. They were left to settle down for 2 minutes and their behaviour was recorded for a further 10 minutes. They were then withdrawn and stored in a gauze-covered bottle with a supply of sugar solution for 24 hours when mortality was noted. A fresh lot of 10 insects was used for every test. Three tests with a DDT paper alternated with three tests with a plain paper were carried out in rapid succession with *Anopheles* on one day, and *Aëdes* on another. The 10 minutes of each test were divided into 5, 2-minute, unit observation periods with *Anopheles* and 10, 1-minute periods with *Aëdes*. At the end of each of these unit periods the number of insects resting on the paper was noted. Meanwhile a continuous record was taken throughout the test of departures by mosquitos from the paper, whether by walking or by flying off. Mosquitos that merely touched the paper in flying past it without coming to rest were not counted as departing. Both stationary and walking mosquitos on the paper were recorded as "settled", provided at least two of their six tarsi were touching it.

With the two sets of figures of number settled and number departing, it was possible to estimate the mean duration of one resting period on the paper. If, for example, there were an average of 10 insects at rest on the paper at any instant during the test and an average of 5 departures occurred during each minute, then it follows that the average insect spent an average of 2 minutes resting on the paper each time it alighted. This method of measuring the duration of resting periods was adopted in order to avoid the labour of recording the behaviour of single individuals. It was suggested originally by Dr. G. S. Hartley, and Staff Sergeant G. E. P. Box, R.A.M.C., worked out its implications more fully.

Let T=total duration of a given test in minutes.

S=average number of mosquitos settled at any instant during the test,

and N=total number of departures observed throughout the test.

Then the total time spent settled by all the mosquitos is $S \times T$ minutes. The number of alightments must be equal to the number of departures, if the number of mosquitos at rest remains constant as is assumed in taking an average figure for number at rest. In fact the number at rest was almost constant in any one test, showing no upward or downward trend, although the number of departures often decreased after the initial excitation engendered by handling the insects. Table I shows a typical example of the results obtained in two successive tests with *Aëdes*.

If the number of departures (N) equals the number of alightments and the total time spent at rest equals $S \times T$, then

$$\frac{S \times T}{N} = \text{mean duration of each resting period in minutes.}$$

In the tests recorded in Table I, therefore, the mean duration of each resting period in the absence of DDT was

$$\frac{S \times T}{N} = \frac{\frac{51}{10} \times 10}{21} = 2{\cdot}4 \text{ minutes,}$$

while the mean duration of each resting period in the presence of DDT was

$$\frac{\frac{90}{10} \times 10}{130} = 0{\cdot}7 \text{ minutes.}$$

The results are independent of the number of mosquitos in the cage (although the results may be affected by mutual disturbance when numbers are large) and independent of whether all or only some of the mosquitos in the cage participate in alightments on the surface observed.

TABLE I.

Detailed results obtained in a pair of successive alightment tests with *Aëdes* on plain and DDT-contaminated papers exposed separately.

Observation Period		1	2	3	4	5	6	7	8	9	10	Total
Plain Paper	No. settled	6	6	5	5	5	5	4	4	5	6	51
	No. of departures ...	8	6	2	0	0	0	1	0	1	3	21
DDT Paper	No. settled	9	10	10	8	8	10	7	10	9	9	90
	No. of departures ...	27	15	18	13	13	10	12	5	8	9	130

Of the 30 mosquitos of each species tested in these experiments without DDT no *Anopheles* and 3 *Aëdes* died in the following 24 hours. Of the 30 mosquitos of each species tested with DDT 1 *Anopheles* and 2 *Aëdes* died in that time. Thus the DDT dose that produced the effects to be described was definitely sub-lethal.

The results of the six tests with each species are shown in Table II. They show three linked phenomena. The presence of DDT :—

(i) reduced the duration of resting periods,

(ii) increased the number of alightments, and

(iii) (in the case of *Anopheles*) reduced the number of insects settled on the paper at any one time.

(i) Duration of resting periods. Resting periods, by both species, lasted several times longer on the plain paper than on the DDT paper. Contact with DDT evidently excited the mosquitos. The magnitude of this effect may be measured by the ratio of the average duration of a single resting period on plain paper to the average duration on DDT paper. This "resting ratio" was 2·7 for *Aëdes* and 3·5 for *Anopheles* (Table II).

(ii) Number of alightments. The number of alightments by both species in the course of a test was greater on DDT paper than on plain paper. In other words the general level of activity was higher on or off the paper in the presence of DDT, a point that was confirmed in the second series of experiments to be described below. The magnitude of this effect may be measured by the ratio of total alightments on DDT paper to total alightments on plain paper. This "alighting ratio" was 3·9 for *Aëdes* and 2·2 for *Anopheles*.

TABLE II.

Results of experiments on alightments on plain and DDT papers exposed separately.

Mosquito	Paper	Individual tests: Test No.	Individual tests: Av. No. settled	Individual tests: Total de-partures	Mean of 3 tests: No. settled	Mean of 3 tests: No. de-partures	Mean of 3 tests: Resting period (mins.)	Resting ratio (E/F)	Alight-ing ratio (D/C)	Distri-bution ratio (A/B)
Aëdes	plain	1 3 5	4·6 5·1 7·1	11 21 61	5·6 (A)	31 (C)	1·81 (E)	2·7	3·9	0·7
	DDT	2 4 6	8·5 9·0 6·9	123 130 109	8·1 (B)	121 (D)	0·67 (F)			
Anopheles	plain	1 3 5	9·0 5·2 6·2	50 41 143	6·8 (A)	78 (C)	0·87 (E)	3·5	2·2	1·6
	DDT	2 4 6	4·0 4·2 4·6	113 183 211	4·3 (B)	169 (D)	0·25 (F)			

(iii) Number of insects settled. The mosquitos alighted more often but stayed for shorter periods on the DDT paper than they did on the plain paper. Had the number of alightments been increased by DDT to the same extent as the duration of each alightment was reduced, then the total time spent by all the mosquitos should have been the same on the two papers. But the resting ratio was not the same as the alighting ratio in either species, as we have seen. In the conditions obtaining the average number of mosquitos settled on the paper was a measure of the total time the mosquitos spent there. We can therefore express the effect of DDT on total time spent on the paper in terms of the distribution of the mosquitos. The magnitude of this effect may be measured by the " distribution ratio ", that is the ratio of average number of insects settled on plain paper to the average number settled on DDT paper. This ratio was 0·7 for *Aëdes* and 1·6 for *Anopheles.*

Thus the presence of DDT did not much reduce the number of *Anopheles* settled on the paper, and actually increased the number of *Aëdes* settled there. This was a consequence of the experimental conditions. The number of insects settled on the paper expressed the partition of insects between the paper and the rest of the glass box. This partition depended in the first place on the insects' preference for resting on the rough paper rather than on the smooth glass. Without DDT the mosquitos were relatively quiet. They were inclined to settle anywhere, even on the glass. With DDT they were more active everywhere. The slight difficulty of settling on the glass was now enough to keep them flying until they reached the paper. They settled readily on the paper and although the DDT soon caused them to leave again, it did not do so as quickly as did contact with the glass. By this means the DDT excitation made the mosquitos return again and again to the paper and increased the effective strength of the paper-glass preference. With *Aëdes* this was enough to outweigh the shortening of each resting period, and the total time spent on the DDT paper was more than that spent on the plain paper. With *Anopheles* the strengthening of the paper-glass preference merely prevented the time spent on the DDT paper from being reduced as much as might have been expected from the shortening of resting periods.

It was noticed that the activity of the two species differed in form. When *Anopheles* moved they nearly always flew, whereas when *Aëdes* moved they either

flew or walked about. Also, a strong impression was formed that *Anopheles* stayed in the air for longer than *Aëdes* when they did fly, as one might expect if flight is the only locomotory outlet for excitation in *Anopheles* but is supplemented by walking in *Aëdes*. Activity was recorded only as departures from the paper. Virtually every move made by *Anopheles* was recorded since it was a take-off, whereas many moves made by *Aëdes* were not recorded since walking was not recorded until it carried the insect off the paper. Hence the records give the impression that DDT excitation was more pronounced in *Anopheles* than in *Aëdes*, although it appeared to be only in the form taken by their excitation that the species differed in fact.

2. *DDT-treated and untreated surfaces exposed together.*

The same apparatus was used here as in the first series of experiments, except that two adjacent walls of the glass box were lined with filter paper and the box turned through 45° so that the corner where the two unlined walls met was pointing toward the observer. One of the back walls was lined with plain paper and the other with DDT-impregnated paper, the DDT density being as before. An equal number of tests were done with the DDT paper on the left and right sides of the box.

In the first two tests with *Aëdes* about 30 mosquitos were used at once, counts of settled mosquitos were taken every 2 minutes and each test continued for 20 minutes. The insects used for the first test were used again in the second, having been left in the box during reversal of the positions of the DDT and plain paper walls. The other two *Aëdes* tests and the four *Anopheles* tests were carried out as in the first series of experiments: mosquitos inserted and left for 2 minutes, departure counts then started and continued for 10 minutes and counts of settled mosquitos made at the end of each minute. Counts were taken for the DDT and plain walls simultaneously but recorded separately. The results are given in Table III. The first two *Aëdes* tests are evaluated separately from the second two for the above reasons while all four *Anopheles* tests are evaluated together. The mortality among the experimental mosquitos in 24 hours was again negligibly small.

TABLE III.

Results of experiments on alightments on plain and DDT papers exposed together.

Mosquito	Individual tests					Mean of tests				Resting ratio	Alighting ratio	Distribution ratio
	Test No.	DDT position	Paper	Av. No: settled	Total departures	Paper	No. settled	No. departures	Resting period (mins.)			
Aëdes	1	L	plain	7·4	68	plain	6·5	56	2·35	1·4	1·3	1·1
			DDT	5·7	68							
	2	R	plain	5·5	43							
			DDT	5·8	73	DDT	5·8	71	1·63			
	3	R	plain	5·0	66	plain	5·4	69	0·78	1·3	1·1	1·3
			DDT	4·1	75							
	4	L	plain	5·7	71							
			DDT	4·5	74	DDT	4·3	75	0·58			
Anopheles	1	L	plain	2·5	47	plain	3·4	78	0·44	1·7	0·9	1·8
			DDT	1·3	54							
	2	R	plain	5·1	118							
			DDT	1·5	101							
	3	L	plain	3·2	74	DDT	1·9	73	0·26			
			DDT	2·3	64							
	4	R	plain	2·8	74							
			DDT	2·3	73							

It will be seen that the resting ratios in the present series were only 1·3 for *Aëdes* and 1·7 for *Anopheles* (Table III), as against 2·7 and 3·5, respectively, in the first series (Table II). The average duration of each resting period on DDT was about equal in the two series but the duration of each resting period on plain paper was halved for both species when DDT was exposed in the same box. Activity anywhere in the small box containing DDT was greater than in the box bare of DDT. This confirms that excitation due to contact with DDT persisted after the insects had left the DDT surface. In the second series of experiments (Table III) the DDT and plain papers were always exposed together in the same box. Mosquitos excited by DDT were not driven back to the DDT paper as often as they were in the first series because there was now a second, untreated piece of paper available. We have here a direct comparison of behaviour on DDT and on plain paper, for the effects of DDT excitation on the paper-glass preference are the same or nearly so for both papers. We now find that departures from the plain paper are almost as frequent as those from the DDT paper, as the small alighting ratios indicate. The small resting and alighting ratios are reflected in small distribution ratios. Both species spent more time on the plain than on the DDT paper, but very little more.

The differences between the species may be explained by the different forms their activity took. The greater amount of flying done by *Anopheles* makes its resting and distribution ratios appear greater than those of *Aëdes*. For the same reason the absolute number of *Anopheles* found settled on DDT or plain paper was consistently smaller than was found with *Aëdes* in this series of experiments where DDT was always present.

3. *Reaction to light in the presence of DDT.*

The arrangements for these experiments are shown in fig. 1. The mosquitos were first released in a small " exposure chamber " (EC) whence they could emerge into two " escape cages " (DE and LE) through ports in the ends of the exposure chamber. The exposure chamber was a metal cylinder 9 cm. long and 9 cm. in diameter. Its curved walls were lined with filter paper and its ends closed with cellulose acetate sheets pierced by a central hole 18 mm. in diameter. The cylinder lay horizontally, each end pressed against a 6·5 cm. diameter opening in the wooden end of one of the escape cages, which were 37×27×24 cm. high, the ends away from the exposure chamber being mosquito netting (NN). The circular openings in the cage-ends were fitted with sliding wooden doors (WW), while the cylinder could be closed off independently by glass plates (GG) sliding over its two ports. One of the escape cages was darkened with a cloth cover (DE). The only light (L) in the room came from a single, paper-screened lamp arranged in line with the cages and 2 m. along the bench from the netting end of the uncovered escape cage (LE). The light was so dim that the mosquitos flying in the light escape cage could be discerned only with difficulty.

The experimental procedure was to blow 9–11 female mosquitos into the exposure cage and leave them there with the ports closed for two minutes, the sliding wooden doors of the escape cages being open. The glass plates over the escape ports were then withdrawn very gently. At the end of a further three minutes the wooden cage doors were slid into place, the exposure chamber lifted from between the cages and the mosquitos remaining in it counted and withdrawn at once. Mosquitos in the two escape cages were then counted and withdrawn into a separate storage container.

This procedure was repeated as quickly as possible in a regular succession of tests on mosquitos from the same stock cage. Alternate tests were done with an exposure chamber lined with DDT-impregnated paper and one lined with plain paper. The DDT paper was impregnated with acetone solution to a density of about 300mg. DDT per m², not in this case by dipping but by hand distribution from a syringe.

The plain paper was treated similarly with acetone alone. Both papers were allowed to dry thoroughly before use.

In the experiments on *Anopheles* the positions of the lamp and apparatus were reversed on the bench after eight tests (four DDT and four plain) and the two escape cages were reversed as between the light and dark positions after every four (two DDT and two plain) tests, there being eight DDT and eight plain tests in the whole series. Whichever end of the DDT exposure chamber was directed toward light in one test was directed toward dark in the next test with this chamber, the plain chamber being treated similarly. The same procedure was adopted for *Aëdes* but circumstances prevented the full series of tests from being completed so that there were seven instead of eight tests of each type. The *Aëdes* were 2–3 days old, sugar-fed females. The *Anopheles* were females of unknown age and mostly contained blood, eggs or both. They were used during the active phase of their diurnal behaviour cycle, at a time of day when they had been kept in darkness or very dim light after 16 hours of bright light.

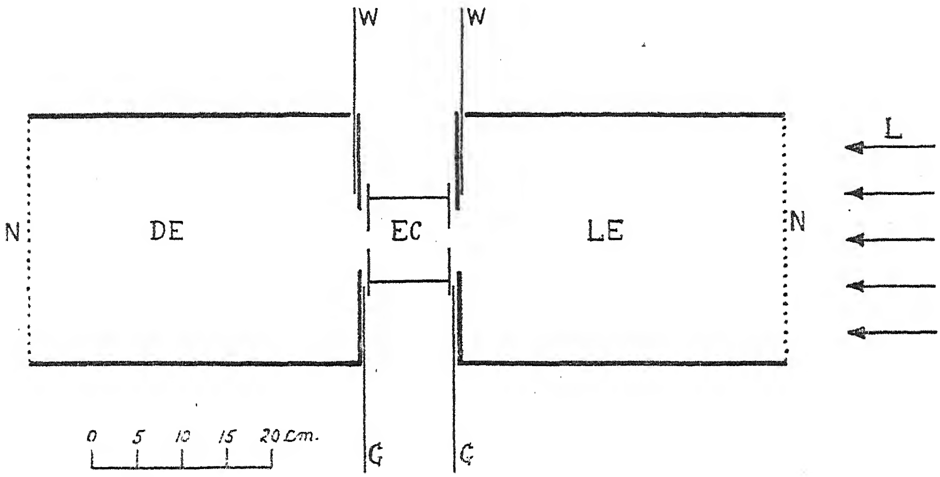

Fig. 1.—Apparatus for determining the effect of DDT on responses to light. For explanation see text.

None of the 140 *Aëdes* used died in the subsequent 24 hours. Some deaths occurred among the *Anopheles*, this species being more liable to injury during handling. The complete *Anopheles* mortality figures were as follows:—plain chamber, 14 out of 67, or 21 per cent. of those remaining in the exposure chamber, and 4 out of 14, or 29 per cent. of those that escaped, making 18 out of 81, or 22 per cent. of the total; DDT chamber, 7 out of 28, or 25 per cent. of those remaining and 5 out of 53, or 9 per cent. of escaped, making 12 out of 81, or 14 per cent. of the total. Hence the effects to be described were produced in both species without the mosquitos having picked up a lethal dose of DDT.

The results (Table IV) showed that the presence of DDT altered the behaviour of both species, although not in quite the same way. Fifty-nine per cent. of the *Aëdes* escaping from the plain exposure chamber went to light and 41 per cent. to dark, a distribution not significantly different from 50 per cent. to each ($\chi^2 = <1$). But every one of the *Aëdes* escaping from the DDT chamber went to light. Forty-one per cent. of all the *Aëdes* used escaped from the plain chamber and 54 per cent. from the DDT chamber, but these figures are not significantly different ($\chi^2 = 2 \cdot 3$ for one degree of freedom, $p = 0 \cdot 15$). Over 80 per cent. of the *Anopheles* escaping from the

exposure chamber went to light with or without DDT, but only 17 per cent. of all the mosquitos used escaped from the plain exposure chamber, whereas 65 per cent. escaped from the DDT chamber.

Thus, DDT did not significantly increase the number of *Aëdes* escaping from the chamber, whereas it greatly increased the number of *Anopheles* escaping. This may be attributed to the different forms activity takes in the two species, *Aëdes* doing much walking while *Anopheles* mainly flies. Walking mosquitos would tend to stay on the paper and avoid the smooth ends containing the exits from one chamber, so that *Aëdes* would encounter the exits less often than *Anopheles* at a given activity level.

TABLE IV.

Results of experiments on escaping toward light and darkness after exposure to plain and DDT papers.

Exposure Chamber	Plain					DDT					
		Mosquito distribution					Mosquito distribution				
			Escaped to					Escaped to			
Mosquito	Test No.	Re-main-ing	light	dark	Total	Test No.	Re-main-ing	light	dark	Total	
Aëdes	1	8	2	0	10	2	5	5	0	10	
	3	6	1	3	10	4	3	7	0	10	
	5	7	2	1	10	6	6	4	0	10	
	7	6	4	0	10	8	5	5	0	10	
	9	3	4	3	10	10	6	4	0	10	
	11	5	3	2	10	12	1	9	0	10	
	13	6	1	3	10	14	6	4	0	10	
		41	17	12	70		32	38	0	70	Total
		59	24	17	100		46	54	0	100	% of total
		—	59	41	100		—	100	0	100	% of escaped
Anopheles	1	9	0	1	10	2	6	5	0	11	
	3	8	2	0	10	4	3	3	4	10	
	5	9	1	1	11	6	0	10	0	10	
	7	8	1	0	9	8	4	4	2	10	
	9	7	3	0	10	10	5	2	3	10	
	11	10	1	0	11	12	2	8	0	10	
	13	7	3	0	10	14	5	4	1	10	
	15	9	1	0	10	16	3	7	0	10	
		67	12	2	81		28	43	10	81	Total
		83	15	2	100		35	53	12	100	% of total
		—	86	14	100		—	81	19	100	% of escaped

The second point of difference between the species was that the light preference of *Aëdes* was clear in the presence of DDT but not in its absence, whereas *Anopheles* showed an equally pronounced light preference in both conditions. The light reactions of mosquitos are delicately and changeably adjusted to their internal and external conditions in a manner not fully worked out, so that no simple interpretation of a given observation can be relied upon. When agitated both species tend to react positively to light. At other times the sense of their reaction varies according

to whether they are pursuing a host, about to oviposit, about to settle in a resting-place (when they are often negative), or randomly active in the case of a night flier (when they are positive), and so on. Perhaps the present results reflect the fact that the *Anopheles* were tested in dim light during the spontaneously active phase of their diurnal cycle, when they would be expected to be positive to light naturally, whereas *Aëdes* are not markedly positive to light at any time unless agitated. Alternatively, it may be that the *Anopheles* were more agitated through handling than were the *Aëdes*, so that the former were strongly positive with or without DDT. The latter may have been in a borderline condition in the absence of DDT, some individuals being agitated enough to go to light but others less so and going to dark as when about to settle in a resting place.

The two species behaved alike in one important aspect. The percentage of all tested mosquitos escaping to light increased substantially in the presence of DDT, from 24 to 54 per cent. of *Aëdes* and from 15 to 53 per cent. of *Anopheles*. Let us suppose that failure to escape at all from the chamber and escaping toward darkness both lead to renewed contacts with DDT, whereas escaping to light terminates such contacts. This might be the case in a DDT-treated room with open windows. The excitation and strengthened light preference induced by sub-lethal periods of contact with DDT might then drive the insects out of the room and so save their lives.

Discussion.

Gahan and others (1945) gave the first published account of a laboratory experiment on the repellency of DDT to mosquitos (*Anopheles quadrimaculatus*, Say). The authors recognize the excitatory action of DDT in the following words: "Some time after they have been introduced into treated cages mosquitos begin to fly and often try to get out, whereas mosquitos confined in check cages usually rest quietly." For their experiment they put six DDT-sprayed, open-ended boxes and one unsprayed box in a 30-in. cubical cage together with 200 mosquitos. An average of 26 mosquitos were observed resting in each treated box 15 minutes later, 20 at 45 minutes and 16 at 3 hours, whereas there were about 37 mosquitos in the untreated box throughout this period. After 24 hours 152 of the mosquitos were dead, and the authors concluded: "It is apparent that most of the mosquitos that did not remain in the untreated box obtained a lethal dose in the treated boxes before they were repelled."

This conclusion goes beyond the facts. Presumably the authors are referring to the DDT-induced excitation which they mentioned initially when they speak now of the mosquitos being "repelled". From their own observations and from those described in the present paper it must be assumed that their mosquitos were "repelled" in this sense again and again. But they must have made further random alightments on the treated boxes between bouts of flying and so picked up their lethal dose in the course of a series of abbreviated resting periods. DDT-treated surfaces comprised a very high proportion of the available resting surface (the mosquitos evidently preferring the boxes to the cage walls). The mosquitos were left with access to DDT for a far longer time than was necessary to kill them in boxes where all available resting surfaces were treated, as shown by other experiments quoted by the same authors. With so long an exposure period and so great a preponderance of DDT-treated surface most of the excited mosquitos inevitably rested on DDT for a sufficient total time to complete the accumulation of a lethal dose. The situation was similar in the second series of experiments described in this paper. Owing to the preference for resting on paper rather than on glass the two paper walls constituted almost the whole of the effectively available resting area. The total area was small and half of it was treated with DDT. The result was that the time spent on the untreated surfaces was only slightly longer than that spent on the treated, so that no significant reduction in mortality was to be expected as a consequence of DDT excitation.

In such circumstances where treated surfaces are readily encountered it seems probable that DDT excitation, so far from reducing mortality, may actually increase it. This could come about in two ways. Firstly, there is some evidence that a mere increase in locomotory activity on an insecticide deposit can accelerate the pick-up of insecticide (Robinson, 1943, for ticks; for mosquitos see a suggestion by Krupe quoted by Rose, 1944, p. 21). Secondly, excitation will increase the rate of random "sampling" by the mosquitos of all available surfaces. To take a simplified case, suppose a population of resting mosquitos to be distributed uniformly over a small surface half of which is treated with DDT, and that the lethal period of contact with DDT is half an hour. If the mosquitos do not move at all then half of them will have picked up a lethal dose in one hour. Now suppose they have all been in previous contact with DDT long enough to become excited by it. Suppose as a consequence they all change their positions simultaneously but at random at the end of each half-hour. Then three-quarters of them will have picked up a lethal dose in one hour. The more often they change position the more nearly will the proportion receiving a lethal dose in one hour approach 100 per cent.

Where the DDT-treated surface is less readily encountered, say because it is relatively small, DDT excitation could reduce mortality significantly. It was found that even where the two adjacent surfaces were the same size and both were small, resting periods were slightly longer on the untreated surface. Reduction in the relative size of the treated surface must reduce the frequency of random alightments on it. DDT excitation declines after departure from a treated surface, if rather slowly. Less frequent alightments will mean a longer time available for the excitation to decline and will therefore lengthen the time spent on untreated surfaces compared with that spent on treated ones. In this case there would be no acceleration of mortality due to DDT excitation, but the reverse.

In the third series of experiments described here DDT excitation brought about a shift to untreated surfaces because of three circumstances: (i) the relatively small size of the treated chamber, (ii) the small openings from the treated chamber making them difficult to find for insects in the large escape cages, and (iii) the photo-positive behaviour of the excited mosquitos. The same result, with consequent saving of lives, could occur even if the treated and untreated chambers were equally lit, freely-communicating and of the same size, provided they were large, like two rooms in a house. Having become excited in a treated room and so found its way out into an untreated room, a mosquito would be less likely to find its way back again, because the flight involved would be longer than the now unexcited mosquito would be inclined to make.

The term repellency has been avoided deliberately in this discussion so far, except when quoting other authors. It is a loose term, looser than we can afford in view of the importance for applied entomology of the facts to which it refers. For practical purposes most workers would agree that a surface is repellent if insects are found to spend less time and so occur in smaller numbers on it than on other available and comparable surfaces. It is convenient to measure the repellency of an anti-mosquito skin dressing, for example, by the time elapsing before some arbitrary number of mosquitos have alighted and bitten. But it would not be disputed that some repellency persists after that time, for as long as fewer mosquitos appear on the treated skin than on a comparable area of untreated skin. Yet there is a widespread implicit assumption that repellency necessarily involves an immediate withdrawal from a treated surface. A moment's consideration shows that a variety of reactions may give rise to a repellent effect. Reactions may occur at a distance or only after contact with the surface. The contact stimuli may be mechanical or chemical. The reactions may take the form of an increase of merely random activity, or be directed away from the surface. They may be quick or slow to appear and weak or strong in appearance.

As far as we know DDT acts only through contact and then only after a delay of some seconds or even minutes. It produces an undirected excitation before a lethal dose has been picked up. This response is the first symptom of DDT poisoning. In the first series of experiments in this paper, we found that the excitation induced by DDT endowed the DDT surface with an apparent attraction for *Aëdes.* In the second series DDT excitation produced a slight repellent effect. In the third series DDT excitation produced a powerful repellent effect. The same reaction, DDT excitation, occurred in all these experiments but the appearance of repellent effects depended entirely on the particular circumstances. It is suggested, therefore, the use of the term repellency is confined to observed effects on distribution. We cannot use it also to describe the reactions of the insects, as Gahan and others (1945) do, without causing confusion. Repellency is more than a reaction. It is something new that arises when certain reactions take place within certain arrangements of treated and untreated surfaces. It always involves reactions, but repellency itself is a distribution effect ; the occurrence of more insects on untreated than on treated surfaces. Repellency of the type DDT can produce, based on delayed reactions not perhaps of a normal sensory nature, may not have been regarded as repellency in the past. But it can hardly be described otherwise.

We are now in a position to consider the rôle of excitation by sub-lethal DDT doses under field conditions. The occurrence of such excitation immediately raises misgivings over the suggestion made by Buxton (1945) for the selective treatment of those parts of rooms naturally preferred by resting mosquitos, in place of the currently-practiced, general treatment of all surfaces. In the present first series of experiments, where the DDT-treated surface was preferred for resting on account of its roughness, it was found that DDT excitation increased this natural preference. At first sight this seems to support Buxton's suggestion, but the misgivings remain on two counts. Firstly, the strengthened natural preference for resting on paper appeared only because the mosquitos were maintained in a state of DDT excitation through frequent contacts with DDT. In a larger space with a relatively small treated area we should expect a significant repellent effect as discussed above. It may be objected that that argument does not hold because the mosquitos are brought to the treated, naturally-preferred, resting places not merely in the course of random activity but partly by directed reactions. But DDT-excited mosquitos lose their normal preference for dark situations and go to light. If Buxton's proposal were adopted, and the windows were open, the mosquitos might well escape with their lives.

Admittedly, the repellent effect of DDT excitation may not only save the lives of mosquitos but may also remove them from access to a host. In fact it appears that the success of residual DDT may be due partly to destruction of mosquitos but partly also to their being repelled from the vicinity of the host. This has been appreciated by Ribbands (1946), but other workers have discounted DDT repellency because of their conviction that the repelled insects were doomed to die.

Gahan, Travis, Morton and Lindquist (1945) describe how *Anopheles quadrimaculatus* introduced into a treated room started to show DDT excitation in a few minutes and flew to the windows. In one observation on naturally-entering mosquitos, 64 out of the 66 specimens present at 8 a.m. were caught on the closed windows in the following four hours. Ninety-five per cent. of these were knocked down or dead after 24 hours' storage in clean containers. It seems possible that some of these mosquitos had been in contact with treated surfaces for longer than they would have been had the windows not all been closed, for in a further experiment with released mosquitos, when re-catching was continued for only 2 hours, the 24-hour mortality among females was only 70 per cent. Taking the optimistic view that the mosquitos driven out were thereby prevented from biting, it could be said that the anti-malarial action of DDT was to repel temporarily most of the potential

vectors and to kill 70 per cent. of them. It is not very satisfactory to have DDT repellency saving the lives of 30 per cent. of the potential vectors, if only because these will go to swell the reservoir of reproducing mosquitos in the area which may then be enabled to take advantage of the first decline in the toxicity of the DDT deposits. In other words DDT repellency may shorten the duration of control effected by residual DDT. The authors also found that DDT-excited mosquitos continued to bite readily until actually "knocked-down." Hence DDT repellency may give a false impression of the success of DDT in the control of malaria by causing mosquitos that have bitten to disappear from house-catches.

Metcalf and his colleagues (1945) studied the behaviour of *A. quadrimaculatus* in huts in the open. Mosquitos entering and resting in DDT-sprayed huts soon became agitated and flew out again through the open door and windows. In order to see what was the subsequent fate of the escaping mosquitos the exits were closed except for part of one window in which an exit trap was fitted. It was found that virtually all the mosquitos caught in this trap had picked up a lethal dose. But this does not seem to be conclusive evidence that all those escaping from huts with open doors and windows also had picked up a lethal dose. When the trap was used the total exit area was substantially reduced, presumably making egress less easy. This may have prolonged the exposure of the insects to DDT. In view of the possibility that active insects pick up insecticide more efficiently than quietly resting ones, a brief delay in escaping from a treated room might make all the difference between life and death for an excited mosquito.

MacDonald (in discussion on Buxton, 1945, p. 394) was convinced that the reduction in anopheline infestation of sprayed rooms was due to actual destruction of mosquitos and "not due to repellent effect, a point of extreme importance." His evidence was the presence of dead mosquitos and the lack of any increase in the infestation of adjoining, untreated rooms. Nevertheless he remarks that there was no evidence of any reduction in such untreated rooms for which, as he says, "one might legitimately hope" in view of the passage of mosquitos from room to room. The solution of this puzzle is surely that there was both destruction and repulsion of the mosquitos. The mosquitos did move freely from room to room and many were killed so that the numbers in untreated rooms did not actually rise, but neither did they fall since the survivors congregated in these rooms as a result of DDT repellency.

DDT repellency might contribute in another way toward saving the lives of mosquitos where there were naturally-preferred but untreated resting places in treated rooms. Examples of such resting places are spiders' webs (Gahan and others, 1945) and firewood (Senior White, 1945). DDT excitation, maintained as long as the mosquitos did not find the untreated resting places, would subside when these places were found (if the mosquitos did not leave the room) and would enable them to be found more quickly, both effects making for repellency. Speaking of firewood, Senior White says: "In fact, the earlier post-spray catches were nearly all made on it."

There is now plenty of evidence that indoor residual DDT treatment is a very effective means of reducing house-catches of Anophelines (*e.g.* Senior White, 1945; Ribbands, 1946). Unfortunately there is as yet no published evidence that the treatment has an equal effect on malaria. We do not know, therefore, what happens to the mosquitos that fail to appear in house-catches after DDT treatment. Since they may be repelled without being killed, and may bite before being repelled even if they die later, due caution is necessary in anticipating the success of residual DDT in the control of malaria.

Where effective control demands nothing less than the actual destruction of the mosquitos, as in aircraft, DDT repellency might very seriously reduce the effectiveness of residual DDT. Mosquitos could survive by resting preferentially on untreated surfaces, for example among the cargo. For that reason it would be unwise to use residual DDT in aircraft except to supplement aerosol spraying (*cf.* Madden, Lindquist & Knipling, 1945). On the other hand, where DDT is used as a general outdoor application, as in aircraft spraying of jungle, etc., DDT excitation should not impair but rather enhance the killing power of the treatment, for reasons already given (p. 602).

The effect of DDT excitation on the success of control measures against other insects depends on the circumstances as much as it does with adult mosquitos. Cragg (1945) has shown that sheep blowflies alighting on a DDT-treated fleece become so excited they cannot oviposit. If the fleece is sufficiently attractive to them they remain on it, although excited, long enough to collect a lethal dose of DDT. But if they are removed from the fleece before their normal stay is completed they do not all die. The destruction of all the flies that alighted on sheep would not eradicate the fly population for breeding can occur elsewhere. But eradication is not necessary. The object of applying the DDT is to prevent oviposition and this object is achieved through the excitatory action of *sub-lethal* doses of DDT. If there were no such excitation DDT would fail to prevent "strike", even if the flies died after oviposition.

The control of mosquito larvae appears to be effected in a similar way, to judge from some preliminary experiments by Maple (1945). The excitation and ataxia induced by DDT in mosquito larvae causes them to break away from the surface film containing the DDT and makes them incapable of swimming up to it again. But if the incapacitated larvae are removed from the bottom of the vessel to a thin film of clean water, they can recover. The object of treating the water of mosquito breeding-places with DDT is to kill the larvae. The DDT appears to achieve this object not by killing them outright, but because the symptoms produced by *sub-lethal* doses lead to death by drowning. In other cases such as the termite-proofing of wood (Wolcott, 1945), there may be no hope of reducing appreciably the whole population of potential attackers, yet entirely satisfactory control may be achieved through the repellency of DDT alone.

In such cases DDT excitation appears to be wholly advantageous for the end in view. But this may not be so with house- and tsetse-flies where the object of control measures is often eradication. DDT excitation leading to repellency might protect treated cattle from tsetse bites but the flies could bite untreated game, reproduce and persist as a standing threat to the cattle. DDT treatment may help to clear rooms of flies but unless repelled flies all die before oviposition they will maintain the local population, ready to re-infest the treated rooms as soon as the DDT deposits lose their toxicity. In such cases, as in the case of adult mosquitos, DDT-repellency may shorten the period of control by residual DDT.

To sum up: the excitation and other symptoms produced by sub-lethal DDT doses may be advantageous or disadvantageous according to the circumstances in each case. In any case they cannot be ignored. It might be added that all these considerations also arise with any DDT carriers or other "residual" insecticides that have similarly irritant properties. They arise with particular force in the case of DDT only because it is used mainly for its residual effect.

DDT must be regarded as acting in two contradictory ways simultaneously. It acts as a lethal agent on the one hand, and as an excitant and thereby sometimes a repellent on the other. It should be possible to favour whichever mode of action the circumstances demand. If the more desirable effect is repellency, then the DDT should be distributed in such a way that the insects are sure to encounter it

and develop the first symptoms of poisoning before they can do any damage. This is the way DDT on the fleece controls sheep blow-fly "strike" (Cragg, 1945). But DDT on water is at present unable to control oviposition by Anophelines (Ribbands, 1946), probably because their contacts with the water surface are very fleeting (Bates, 1940).

It may be desirable to use the lethal effect only and eliminate the repellency. To that end the comparative effects of different physical forms of DDT deposit call for study. A start has already been made on these lines (*e.g.* Barnes, 1945). The objective of such work would be to reduce the lethal contact time to the point where the insects will have already picked up a lethal dose before DDT excitation drives them off the treated surface. This might be achieved by increasing the rate of penetration through the insect's cuticle until the accumulation of a lethal dose and the start of excitation were almost instantaneous and simultaneous, as with the pyrethrins and some insects. But if that is not possible, the objective could still be achieved by slowing down penetration instead of accelerating it. In other words the rate of DDT "pick-up" should be increased without a commensurate increase in the rate of penetration. The insect should be made to acquire and retain the maximum *external* load of DDT, such as a dust of fine crystals, a film of slowly-penetrating oil or in some other form. This should not contribute toward immediate excitation. But it should provide a reservoir from which DDT would continue to penetrate into the insect after it had left the treated surface, and so ensure its eventual death.

Summary.

1. Mosquitos often recover completely after showing the preliminary symptoms of DDT poisoning.

2. The effect of contact with DDT on the activity and distribution of mosquitos has been studied in a small cage, exposure times being kept below that necessary to kill the insects.

3. The duration of single resting periods on DDT-treated surfaces was several times shorter than resting periods on untreated surfaces, provided the mosquitos had had no recent access to DDT.

4. Mosquitos that had been in recent contact with DDT rested only slightly longer on untreated than on DDT-treated surfaces.

5. Mosquitos excited by DDT moved preferentially toward light.

6. DDT-excited *Aëdes aegypti* and *Anopheles maculipennis atroparvus* behaved similarly although their activity differed in form.

7. Excitation by DDT rendered treated surfaces weakly or strongly repellent or even attractive, depending on the circumstances. It is argued from this that repellency is not a reaction but a distribution effect; and that DDT repellency must be reckoned with in the use of residual DDT for mosquito control.

8. Some examples are given to illustrate how the symptoms induced by sub-lethal doses of DDT enter into other DDT applications, advantageously or otherwise according to the type of control DDT is intended to exert.

9. Research may be needed on methods of retarding rather than accelerating the penetration of insecticide into insects.

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APHANUS (HEM., LYGAEIDAE) IN STORED GROUND-NUTS.

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In April, 1944, *Aphanus littoralis*, Dist., was found damaging stored ground-nuts in the Adamawa Province of Nigeria, at Yola and Lau on the Benue River about 120 miles apart. The species had not hitherto attracted attention in this country, but has since been found also in the Bornu, Kano, Benue and Niger Provinces, and to be associated by native farmers with ground-nut plants stacked at harvest to dry. This paper records studies of the pest made at Yola between May and October 1944.

The only published record of the species that has been traced is the original description (Distant, 1918) reporting it from Nyasaland and the Sudan. According to Mr. W. E. China of the Natural History Museum (in litt.) specimens of *littoralis* from Somaliland occur in the National Collection and in his opinion it is probably identical with *Aphanus sordidus*, F.

Aphanus sordidus, F., was first described by Fabricius (1787) and later re-described by Distant (1903). Although it is usually regarded as an oriental species, it has been recorded from West Africa by Stål (1874) and Roubaud (1916), and from the Gulf of Oman by Macan (1937). As a pest of ground-nuts it has been reported from Senegal (Roubaud, 1916; Risbec, 1941), Coimbatore (Ramachandra Rao, 1928), and Bombay (Deshpande & Ramrao, 1915; Kasargode & Deshpande, 1921). It is also reported as attacking *Sesamum* in Bombay and Calcutta (Deshpande & Ramrao, 1915; Kasargode & Deshpande, 1921; Distant, 1903), *Carthamus tinctorius*, L., in Bombay (Deshpande & Ramrao, 1915), millet in Mandalay (Ghosh, 1924), and *Solanum nigrum*, L., in Canton (Hoffmann, 1931 & 1932).

Storage Conditions.

In the Benue Valley ground-nuts are usually stored (shelled and in bulk) in large corrugated-iron sheds, but during the war extra stores of mud-and-thatch were built and it was in these that the infestation at Yola developed. They were noticeably cooler than metal sheds about a mile away, which were uninfested, the average day temperature (85°F.), over a period of nine days in June, being 2°F. above the shade temperature for the same period, but 10°F. below that of the metal stores. This is suggestive, but it must be noted that the infestation at Lau (not inspected) was reported from metal stores.

Description of Infestation.

Of the eight mud stores concerned, only six were infested, this being noteworthy in that the heaviest infestation was in the stores most nearly approached by a belt of vegetation on swampy ground a few yards off, and was progressively less in the direction of the two uninfested stores, that were furthest away.

The stores were filled during March and the infestation reached its height early in May. Thereafter it declined and was of negligible proportions by the end of July, while in September it was difficult even to find specimens for study.

During the day, nymphs and adults were found either inside the stores congregated on the nuts near the walls, or outside under the coarse grass matting protecting the mud walls against rain. So numerous were they that their movements when disturbed were readily audible, and accumulations of exuviae as much as half an inch deep were

to be seen in the most frequented places. From just before sunset to just after sunrise most were found outside in search of moisture, scattered around thickly for many yards on the ground and vegetation. They were seen feeding on grasses, sedges, and cotton and banana plants, all of these having a more or less burnt appearance. To a lesser extent they were seen on Mango and Baobab trees, and sucking at the damp earth at the edge of the swampy area mentioned, but never on the sugar cane that was plentiful.

Nature and Extent of Damage.

All stages feed by sucking oil from the ground-nut kernels. No puncture is visible afterwards, but sucked kernels are wrinkled, light in weight, have an oil-soaked appearance (and are therefore darker than usual), and rustle when moved. From Table I it may be seen that weight may be reduced by more than half, that much oil may be removed, that damage may lead to an increase of free fatty acids, but that volume is little affected. Roubaud (1916) reports a loss in weight of 7·6 per cent. in sixty hours in a small experiment, while Kasargode & Deshpande (1921) found a one-third loss of weight in a bin of nuts a year old. They also found a reduction of germinative power from 98 to 56 per cent. over the course of three months' attack, and that nuts may become so bitter and rancid as to be useless for eating.

TABLE I.

Comparing selected sound and damaged whole Kernels.

Condition	Weight of 100 kernels	No. of kernels filling a cigarette tin	Oil content	F.F.A. content
	ozs.		Per cent.	Per cent.
Sound	1·72	344	50·57	1·95
Damaged	0·78	344	17·51	8·28

Percentages are of oven-dry weight of sound kernels.

Borings 3 inches in diameter were made in infested and uninfested stores, with results given in Table II. It will be seen that damage did not extend more than 3 in. or so below the surface of the bulked nuts. It was found further that it was more or less confined to kernels within a yard of the walls, and was finally assessed as not affecting more than 0·05 per cent. of the nuts in storage (they were stored ten feet deep), despite the alarming numbers of bugs present.

TABLE II.

Showing Depth to which Damage extended in stored Kernels.

Place of Boring	Weight in Ounces of 100 Whole Kernels						
	First Inch	Second Inch	Third Inch	Fourth Inch	Fifth Inch	Sixth Inch	Seventh Inch
Uninfested	1·59	1·58	1·54	1·54	1·60	1·58	1·53
Infested	1·22	1·24	1·35	1·52	1·60	1·58	1·56

Each value shown is an average of ten borings.

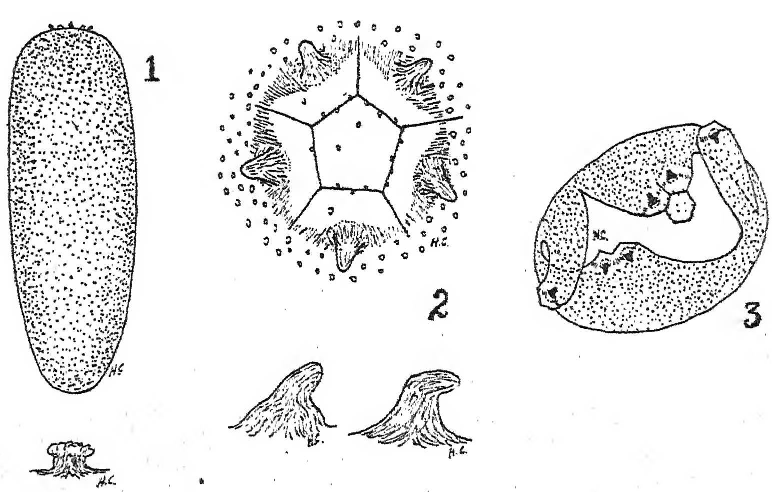
A few kernels were stored in jute bags. Eggs were found in the weave of the bags near the inner side, and a few of the smaller nymphs were found amongst the kernels. Adults and the larger nymphs were seen attacking kernels by thrusting their beaks through the jute material.

Other writers (Roubaud, 1916; Kasargode & Deshpande, 1921; Risbec, 1941) report severe damage to nuts drying at harvest time saying that the bugs are capable of attacking the kernel through the shell. Damage is the same as that already described. As far as this country is concerned, it may be noted that damage in the field has not been sufficiently severe to have come to the notice of native farmers.

Life-History and Description.

Before describing the various stages in detail, a few general observations may be made. All instars are agile and active, mainly at night. After each moult the skin of the insect is white or at least very pale, but colours rapidly and assumes its final hue in an hour or so. The transitions are preceded by sluggishness and a slight swelling and darkening. The imago has three joints to all tarsi, while all the nymphal instars, of which there are six, have only two. All the nymphs have a black terminal abdominal segment, and four median dorsal black spots situated across the joints of abdominal segments 3–4, 4–5, 5–6 and 7–8, there being none between segments 6 and 7.

Egg: The eggs are sausage-like, about 1·2 mm. long and 0·45 mm. in diameter, and are quite tough-shelled. When laid they vary from very pale yellow to very pale brown, but change through pink to a full red during incubation. The surface is closely set with stud-like spines, but so small are they that the eggs are smooth, shining, and translucent to the unaided eye. They are bluntly rounded at the anterior end, slightly tapered and less bluntly rounded at the other, and usually bulge slightly to one side (fig. 1).



Figs. 1–3.—*Aphanus littoralis*. (1) Showing an egg (×40) and one of the studs (×800) covering its surface; (2) Showing crown of spines at apex of egg (×200) and the two types of spines found (×400); (3) Showing mode of hatching—dehiscence of a six-spined egg (×67 approx.).

At the anterior end the eggs are surmounted by several spines arranged regularly in a circle; more often than not there are five, but the number may vary as shown in Table III. Were there fewer than three, the arrangements to be described could not obtain, while more than eight would probably require a larger circle than is found. Some eggs have spines of one type, others of another. One type rises from a swollen base and curves outward to a bluntly rounded tip; the other rises from a less swollen base and is well described as resembling the hooks on some lace-up boots. Both

types vary from very pale to very dark brown, those on any one egg being all of the same tint. With the darker spines, the colouring spreads across the inter-spinal spaces (figs. 1 & 2).

TABLE III.

Showing the Variation in Spine Number.

No. of Spines	3	4	5	6	7	8	Total
Proportion ...	Per cent. 0·1	Per cent. 10·2	Per cent. 52·7	Per cent. 33·2	Per cent. 3·6	Per cent. 0·2	Per cent. 100·0

100 per cent.=1,957 eggs examined.

Within the circle formed by the spines, the chorion is transparent, appears to be thinner than it is elsewhere, and bears a pattern of raised lines. These form a central regular polygon, with a line extending radially from each angle into the inter-spinal spaces. The spines are nearly always of the same number as, and opposite, the sides of the polygon, but occasionally one is missing; that is, there is a vacancy opposite one of the sides of the polygon (fig. 2).

The arrangement just described is a hatching device, as may be seen very clearly after hatching has taken place. The raised lines are sutures formed by the fusion of the thickened edges of the parts into which the pattern divides the circle. The shell ruptures along some of the sutures, and the splits, once started, extend into the thicker tissue beyond the spines, to give egress to the nymph (fig. 3).

The hatching device, or some part of it, seems also to play a part in respiration. If the crown of a developing egg be painted with watery gum-arabic it stops developing, whereas if the whole egg except the crown be so painted it continues to develop and hatches as usual. In no case were spines seen to serve as a means of attaching eggs to another object.

TABLE IV.

Showing Effect of Heat on Rate of Incubation.

Average Fahrenheit Temperature	75°	80°	85°	90°	95°
Average Incubation Period in Days	8·3	7·2	6·2	5·2	4·2

Values taken from a graph of 72 observations.

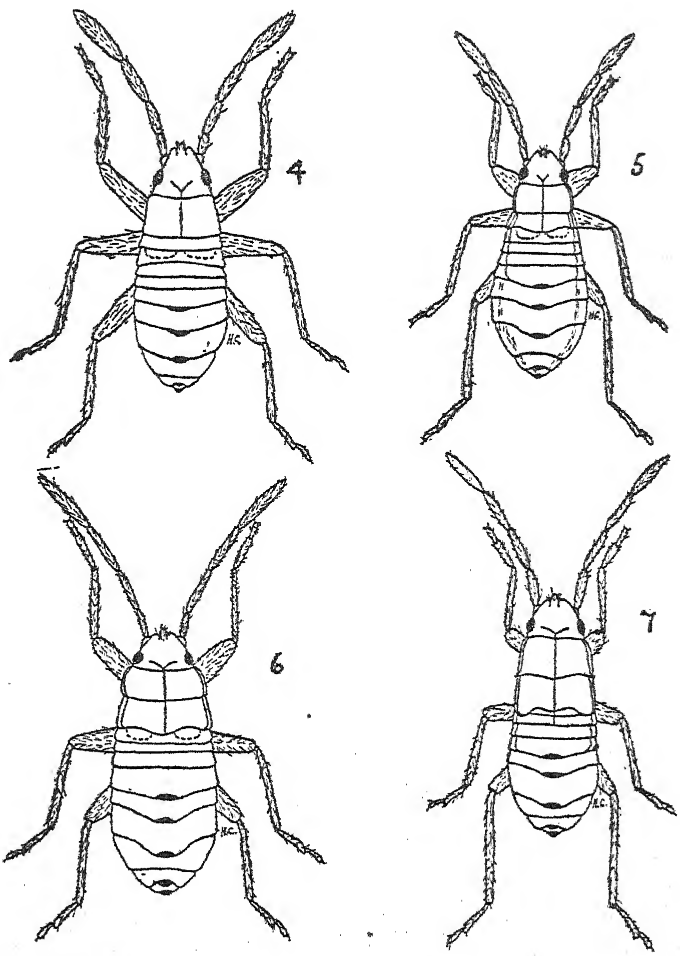
In cool weather eggs may take a week or so to hatch, while in hot weather they may hatch in less than five days. With maxima not exceeding about 82°F., Roubaud (1916) found incubation to take eight days (Table IV).

The eggs have received little attention from other writers.

First Instar: The first instar is not normally seen except vaguely through the chorion, because it casts its skin as it hatches, the nymph thus emerging in the second stadium. It is of interest, however, in that the front of the head bears a pointed boss with which to rupture the chorion for hatching. The cast skin is often to be found lodged in the mouth of the empty chorion, the boss, which does not persist in subsequent instars, being plainly visible when magnified.

Second Instar: The second instar varies from 1·5 to 1·8 mm. in length and up to 1 mm. in width, and is pale pink as it emerges. When fully coloured the head and prothorax are shiny black, and the abdomen and metathorax orange. There may be

patches of deeper orange between the dorsal spots, but there is no indication of the colour pattern of the succeeding forms. The wings are represented only by two small black patches of colour on the metanotum, while the mesonotum shows as a distinct light band across the body (fig. 4).



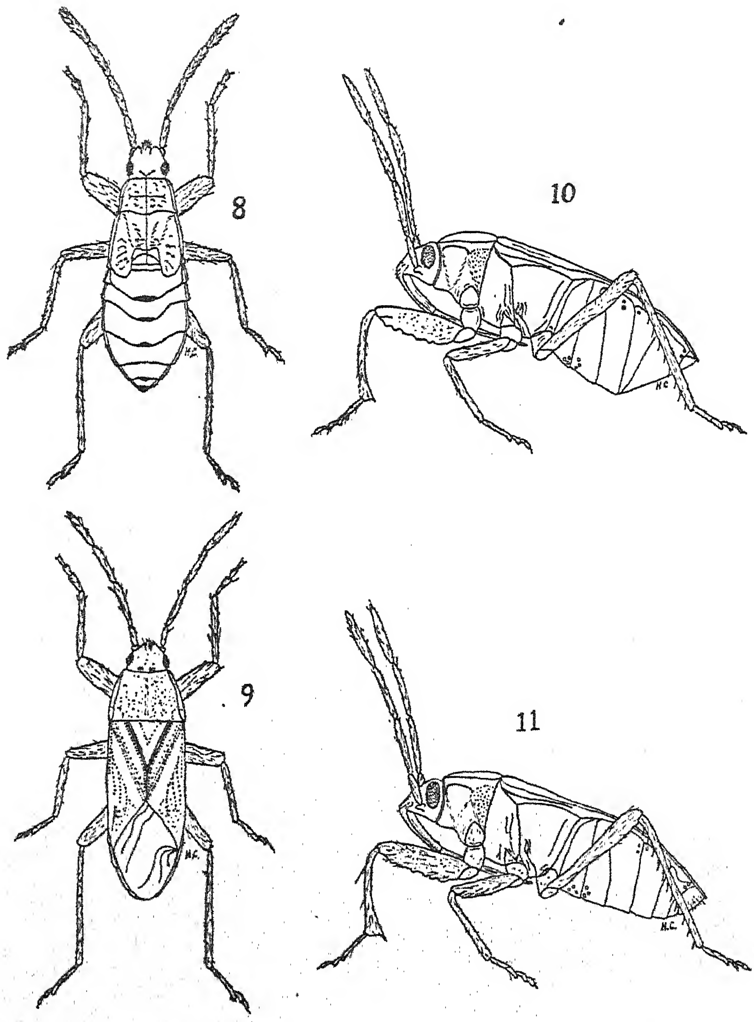
Figs. 4–7.—*A. littoralis.* (4) 2nd instar (×17 approx.); (5) 3rd instar (×12 approx.); (6) 4th instar (×10); (7) 5th instar (×7 approx.).

Third Instar: The third instar varies from 2·0 to 2·7 mm. in length and up to 1·5 mm. in width. As seen from above, the head, prothorax and mesothorax are shiny black, while the abdomen and metathorax are patterned in red and varying shades of brown. The mesonotum is about half as long as the pronotum. The black patches of colour representing the wings are usually separated from the hind margin of the mesonotum by an almost imperceptible whitish line (fig. 5).

Fourth Instar: The fourth instar varies from 2·5 to 4·0 mm. in length and up to 1·7 mm. in width, and is very similar in general appearance to the third instar. It differs, however, in having the mesonotum about as long as the pronotum, and usually lacks the fine white line mentioned (fig. 6).

Fifth Instar: The fifth instar varies from 3·5 to 5·5 mm. in length and up to 2·5 mm. in width. As seen from above, the head and prothorax are shiny black, and the abdomen is patterned as in the two preceding instars. The wing rudiments are black and extend more or less to the posterior margin of the metanotum (fig. 7).

Sixth Instar: The sixth instar varies from 5·0 to 7·8 mm. in length and up to 2·9 mm. in width. As seen from above, the head and thorax are obscurely patterned in red and brown, while the abdomen is coloured as in the three preceding instars. The wing rudiments are brown, and wrinkled and usually extend over the third abdominal segment (fig. 8).



Figs. 8–11.—*A. littoralis*. (8) 6th instar (×5); (9 & 10) Adult female bug (×4); (11) Adult male bug (×4).

Imago: In view of the likelihood that *Aphanus littoralis* and *A. sordidus* are synonymous, it seems advisable to describe the Nigerian specimens in some detail, employing the differentia used by Distant in his descriptions. They are small agile bugs from 7 to 9 mm. long and up to 3 mm. wide. The head and eyes are dark brown

or black ; the two ocelli are red or amber according as the light strikes them. The antennae are slender and from 5 to 6 mm. long, and four-jointed ; the distal part of each segment is darkened, while the proximal third of the terminal segment is conspicuously yellow. The rostrum is about 4 mm. long, with the first segment extending to the base of the head or slightly beyond. The pronotum is brownly punctate except on the lateral margins ; the anterior half is red-brown to dark brown, the posterior half ochraceous ; at the anterior margin are three inconspicuous ochraceous spots, one being median and the other two more or less behind the ocelli. The scutellum is mostly ochraceous, but with a dark brown or black base and a yellow apex ; it is brownly punctate except on the margins. The wing membranes are smoky brown with paler mottlings, and a dark patch near the base. The coria are ochraceous and brownly punctate. The whole body is black or very dark brown beneath, with yellow spots or markings as follows : along the edge of the abdomen, on the margins of the acetabulae, and on the posterior margins of the prosternum and metasternum. The legs are ochraceous, brown spotted, and sparsely brownly punctate ; the femora of the forelegs are swollen and have a row of prominent blunt processes along the lower side (fig. 9).

The sexes are much alike, but may be distinguished quite readily by the arrangement of the abdominal segments. In the female the abdomen is deep, and the fifth and sixth segments taper ventrally to an obtuse point ; in the male the abdomen is shallow and rounded and the segments are normal. The ovipositor folds double and lies hidden in a groove extending from the obtuse point just mentioned to the end of the body ; it is about 4 mm. long when extended. The penis may be dissected from the more or less globular terminal segment as a minute springy coil of four or five turns, about 7 mm. long when extended (figs. 10 & 11).

Mating, accomplished with the pair end to end and facing opposite directions, has been seen as soon as three days after eclosion, and recurs at irregular intervals throughout adult life.

Egg-laying usually begins about seven days after eclosion and continues steadily until death. Females kept under observation laid an average of well over a hundred eggs (246 in one case). In the ground-nut stores eggs were found in the webbing spun by a small caterpillar working in the nuts, in the weave of the jute bags, and in the mixture of dust and rubbish to be found on the floors. In breeding experiments teased cotton-wool was the most popular repository, but some eggs were found thrust into pinholes and crevices in corks. In the field, eggs have been found in large numbers in samples of soil taken from the edges of heaps of ground-nut plants drying at harvest. Roubaud (1916) describes them as being laid in sand in clusters (*paquets*) of six or so.

The average length of life of adults of both sexes kept under observation was about 17 days, 39 days being the longest recorded.

Life-Cycle : Under observational conditions the life-cycle was found to take nearly two months, as shown in Table V.

TABLE V.

Summarising Observations on the Life-Cycle.

Number of observations	Stage	Duration in days		
		Average	Min.	Max.
88	Egg and First Instar	6·4 *	4·8	8·2
11	Second Instar	8·0 *	5·8	16·0
10	Third Instar	11·8 *	4·0	16·0
9	Fourth Instar	7·5 *	4·4	14·8
11	Fifth Instar	5·3 *	4·4	7·0
20	Sixth Instar	8·3 *	6·5	15·0
13	To laying of first egg	6·9	3·4	10·4
	Total	54·2	—	—

*Total 47·3 days, as compared with 42·9 and 44·1 days for the only two complete observations.

During studies of the life-cycle, a great many nymphs died in ecdysis, particularly in the transition from the third to the fourth instar, and as a result only two specimens were followed through from egg to adult. To offset this, nymphs were captured from the stores, sorted into instars, and reared individually. In preparing Table V, in incomplete cases, only stages after the one in which capture was made, and before the one in which death occurred, were included in assessing the averages and ranges shown.

Natural Enemies.

Two species of cricket, *Gryllulus* (*Gryllus*) *domesticus*, L., and *Gryllodes sigillatus*, Wlk., were observed to feed on the pest and its eggs, one specimen having been seen to eat 25 eggs in less than seven hours. It is thought that they may have contributed to the decline of the infestation at Yola.

Risbec (1941) records that *Cephalonomia* sp. (Hym., Bethylidae) parasitises the eggs, but adds that it is difficult to assess its importance.

Control Measures.

Time did not permit of experiments in controlling the pest, but observations suggest that storing in thick bags may be the most helpful method of approach in local circumstances. This has been recommended by Deshpande and Ramrao (1915) for Indian conditions.

It was seen clearly at Yola, and has been emphasised by others (Roubaud, 1916; Kasargode & Deshpande, 1921), that the pest cannot live entirely on stored ground-nuts, but must have access to moisture as well. It should prove helpful, therefore, to remove all vegetation near ground-nut stores in order to deprive the pest of its main source of moisture. This has been recommended by Roubaud (1916) and Risbec (1941) for Senegal conditions. Risbec also recommends that stores should be surrounded at a distance with damp straw, which should be burned as soon as it has attracted a sufficient number of bugs. Presumably this would be repeated. It might be feasible to extend this method to poisoning the water used to dampen the straw, or to do without the straw and merely moisten the ground at intervals with poisoned water.

Spraying with a contact insecticide should be practicable, but tests would first be necessary to find insecticides not affecting the ground-nuts in any way. Two sprays at an interval of two weeks would probably be sufficient for any one outbreak, but would, of course, have to be repeated if, as seems likely, continuous reinfestation from the surrounding countryside occurs. Fumigation of the stores commonly used in this country would be impracticable.

Summary.

A bug identified as *Aphanus littoralis*, Dist., but believed to be synonymous with *A. sordidus*, F., was found infesting stored ground-nuts at Yola, Nigeria. It had not hitherto attracted attention in this country, but was found later to be recognised by native farmers as associated with ground-nut plants drying in the fields at harvest.

The nuts concerned were in war emergency mud and thatch stores which were much cooler than the (uninfested) corrugated-iron stores normally used. This difference is believed to have favoured the infestation.

The adults and nymphs cause damage by sucking the oil from the kernels. Loss of weight and germinative power, and development of free fatty acids and rancid and bitter taste follow. It was found, however, that bugs could not penetrate more than three inches or so into the bulked kernels, so damage was not extensive.

The eggs, adults, and the six nymphal instars are described and figured. The life-cycle was found to take about seven weeks under observational conditions.

Methods of control were not worked out, but bagging the kernels in thick bags is suggested. The removal of all vegetation near the stores, the use of damp straw as a trap, and spraying with contact insecticides are also mentioned.

Acknowledgements.

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THE ERADICATION OF *SIMULIUM NEAVEI*, ROUBAUD, FROM AN ONCHOCERCIASIS AREA IN KENYA COLONY.

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Introduction.

Onchocerciasis is apparently limited in Kenya to three areas, the large Kaimosi-Kakamega Forest; Kodera, Basi, and Riana in South Kavirondo; and Ngoina in the Kericho District. The epidemiology of the disease has been worked out by Hawking (1939), McMahon (1940), various authors (Symposium, 1939) and more recently by Buckley whose findings are as yet unpublished. In Kodera and Kaimosi, the disease is severe and its presence has interfered both with settlement and mining activities; in Kodera the population has been so badly afflicted that the place is sometimes referred to as the "Country of the Blind". The vector of the disease in Kenya is *Simulium neavei*, Roubaud.

Until recently no method of eradicating the insect had been devised and the employment of satisfactory methods appeared to be dependent upon the discovery of the exact breeding habits of the species, and these are at present unknown. However, there is strong circumstantial evidence that *S. neavei* breeds in fast-flowing streams and rivers and it seemed that the effect of DDT on such rivers was worth trying without delay. The use of DDT for *Simulium* control has already been briefly reported by Fairchild and Barreda (1945) and Steward (1946) found that in laboratory trials one part of DDT in 4,000,000 of water caused an "almost complete mortality" of the larvae.

In order to determine the lethal action of DDT on the immature stages of Simuliids in Kenya, a preliminary trial was made in January 1945, on a stream near Nairobi infested with larvae and pupae of *S. elgonensis*, Gibbins. An emulsion was prepared using a 5 per cent. solution of DDT in kerosene plus 5 per cent. Shell M2 cutting oil. This was emulsified in an equal quantity of water and dripped into the river so as to give 2 parts of DDT per million of water for 35 minutes. The stream for 3 miles below the point of application was searched, a week and a fortnight later; no larvae were seen, only dead pupae, whilst above the treated stretch both larvae and pupae persisted in abundance. The result was so dramatic that further tests were regarded as unnecessary and arrangements were made to start a large-scale experiment to eliminate *S. neavei*.

The site for the experiment had to conform to two important conditions; first, it had to be well isolated from other infested districts and second, previous data on the seasonal density of the insect had to be available. Kodera in South Kavirondo fulfilled both these requirements. It lies 12 miles inland from Lake Victoria at an altitude of 4,300 to 4,900 feet and occupies an area of at least 65 square miles. Through it run two tributaries of the River Awach, the Kitare and the Sanda, and nine miles of the former and six miles of the latter were infested with the fly (see fig. 1). The nearest *neavei* area is over six miles to the south across a range of hills and in another watershed. Figures of *neavei* incidence were available in some detail because Kodera had been surveyed in 1939 (by J. P. McM.), and for the last three years it has served as the control of another experiment.

Rainfall figures for the district are given in Table I. The maximum and minimum temperatures of the river water were taken for a few days in September 1946 and gave an average maximum of 21°C. and an average minimum of 18°C. These figures approximate to the optimum ones obtained by Rubtzov (1939) for *Simulium* breeding in Russia.

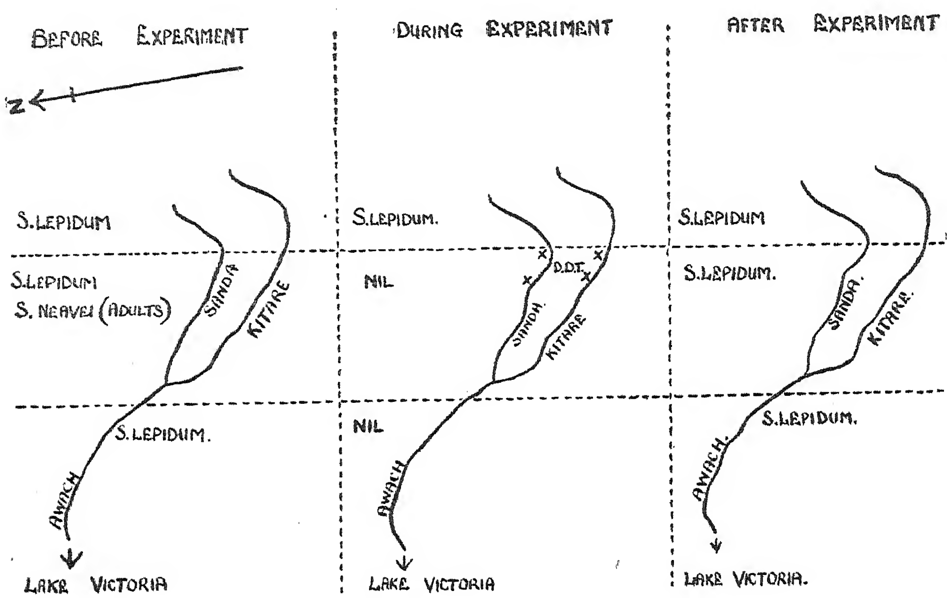

Fig. 1.—Semi-diagrammatic sketches of Kodera.
Infestation with *S. neavei* was confined to the middle zone. *S. lepidum* includes all species of *Simulium* except *S. neavei*. × =Main points of application of DDT.

TABLE I.

Rainfall in Inches, Kodera.

Month	1944	1945	1946
January ...	2·1	1·3	0·3
February ...	1·0	1·4	0·1
March	6·4	0·5	4·2
April	6·9	3·2	13·9
May	Nil	6·4	6·2
June	3·3	4·2	4·8
July	2·5	6·0	3·7
August	8·9	5·3	8·9
September ...	Nil	9·9	
October ...	4·9	3·0	
November ...	3·1	5·0	
December ...	3·3	1·1	

Technique and Applications.

Anti-larval rather than anti-adult measures were chosen because they seemed more likely to succeed.

DDT is practically insoluble in water, and in spirit only a 1 per cent. solution can be obtained, so it was obvious that some form of emulsified concentrate would be necessary. Supplies of a 15 per cent. emulsion (T.P.520) were sent out by the

Colonial Medical Research Committee and proved very suitable. They were supplemented later in the trial by products locally prepared by the East African Industrial Management Board. The best of these was a solution of DDT in toluene (20 per cent. para para) using good quality soap (at the rate of 10 per cent.) as an emulsifier and 1 per cent. Abracol as a stabiliser. When supplies of toluene ran out, a 10 per cent. para para solution in M.K.E. (Medium Kerosene Extract, a Shell Oil Company product) with 20 per cent. soap (serving the dual purpose of emulsifier and stabiliser) was adopted. On one occasion owing to shortages of supplies, an emulsion was prepared in the field using M2 cutting oil, soap and DDT in kerosene.

The preliminary trial had shown that two parts of DDT per million of water were sufficient to kill Simuliids and this was the strength first employed in the applications, though later it was increased to five or more parts per million. These amounts were applied to the water for thirty minutes at a time, ensuring contact between insecticide and larvae for the whole of this period. There were two factors to be considered in regard to the times of dosage ; the minimum length of larval life and the maximum length of adult life. The interval between applications had to be such that any larvae derived from surviving adults would be destroyed. The cycle has been variously estimated as lasting anything from two weeks to two months. To ensure success, a ten-day period was fixed for the first ten applications ; this was subsequently extended to a fortnight and eventually to a month. In regard to the factor of maximum adult life, the treatment had to be continued until it was certain that the last surviving fly had laid its eggs. Again no exact data were available to indicate the correct period ; females of *S. neavei* probably do not live much longer than two months, but DDT was applied for five months to make sure that the last fly had oviposited.

Accuracy of dosage depended upon the use of a satisfactory method of measuring the flow of the water in the rivers. The surface float method is subject to rather gross error and was discarded in favour of measurement over V notches and later over Cippolletti weirs (King, 1939). Portable weirs are unsatisfactory owing to the difficulty of transportation and also they are only suitable for small streams. The best method is probably that in which a current meter is used. It is important that all estimates should be made, not at the dosing point itself, but at or below the place furthest down stream which it is desired to disinfest. This is in order to ensure that water from the tributaries etc., is also included in the reading. Measurements were made on the days of the applications and the amount of DDT required for so many cusecs of water for half an hour's continual dosage was calculated.

The infested area lay along two rivers, the Kitare and Sanda, and for a short distance along the Awach, beyond their confluence. Only two of the many small tributaries of the Kitare and Sanda rivers appeared likely to breed *S. neavei* ; at the beginning of the experiment both of these were dry and they did not have to be treated until the rains were well established. The adult fly is found only in the vicinity of rivers which are (*a*) heavily shaded by trees, (*b*) broken by numerous waterfalls or cascades, and (*c*) usually eroded deeply below the surrounding terrain, preserving thus a localised humid climate. The actual dosing points were therefore selected so as to be well above the stretches of the rivers complying with these conditions and above the upper limit of infestation. Previous experience indicated that fly had never penetrated as far up as these points.

The presence of maize-grinding mills at the dosing points facilitated the application of the emulsion, which was thus intimately mixed with the river water cascading down the chute. First, river water was added to the emulsion in a four-gallon tin, slowly until the water-oil phase was passed and then more rapidly until the tin was filled. The mixture was transferred to a similar tin suspended by ropes over the centre of the aqueduct of the mill (fig. 2). One or more holes in the bottom of this tin had been made to give a standard rate of delivery. For instance, a circular hole $\frac{3}{8}$ inch in diameter, dripped approximately 12 gallons in 30 minutes. When the rivers were in spate several tins were used instead of one. Thorough mixing took place in

the mill chase and again in the numerous cascades along the course of the rivers. It is almost certain that *S. neavei* breeds solely in the latter places and these are the very points where emulsification must be most complete.

Tables II, III and IV show the calendar of the applications, with dosages. Treatment of the two main rivers was begun on 19th January, 1946, and ceased five months later on 22nd June. The two important tributaries were treated on four occasions, which coincided with the last four river dosages.

Fig. 2.—Application of DDT emulsion from a tin suspended over mill aqueduct, Kodera.

TABLE II.

DDT Dosage Record of Sanda River, Kodera.

Date	Cusecs	Dosage in gallons of emulsion	Percentage DDT in emulsion	Parts DDT per million of water
			Per cent.	
19/i/46	1·3	0·5	15	5·1
29/i/46	1·4	0·7	15	6·7
8/ii/46	0·8	1·3	15	20·7
18/ii/46	0·5	0·5	5	4·4
26/ii/46	0·5	0·13	20	5·0
8/iii/46	0·5	0·13	20	5·0
22/iii/46	0·5	1·0	20	35·6
1/iv/46	0·6	0·4 (Upper) 0·4 (Lower)	20	12·2 10·4
11/iv/46	0·4	0·7 (Upper) 1·1 (Lower)	10	18·1 27·1
23/iv/46	3·9	3·0	10	6·8
9/v/46	12·2	7·0	10	5·0
25/v/46	8·6	5·0	10	5·2
22/vi/46	17·5	2·5	10	1·3

TABLE III.

DDT Dosage Record of Kitare River, Kodera.

Date	Cusecs	Dosage in gallons of emulsion	Percentage DDT in emulsion	Parts DDT per million of water
			Per cent.	
19/i/46	6·0	2·5	15	5·5
29/i/46	9·1	2·0	15	3·2
8/ii/46	5·11	2·0	15	5·2
18/ii/46	3·2	4·0	5	5·5
26/ii/46 ...	5·25	1·75	20	5·9
8/iii/46	5·0	1·7	20	6·1
22/iii/46	{10·8 { 7·0	3·0 (Lower) 0·75 (Upper)	20	4·9 Token*
1/iv/46	6·1	{ 1·9 (Lower) { 0·15 (Upper)	20	5·5 Token
11/iv/46	6·3	{ 3·8 (Lower) { 1·0 (Upper)	10	5·3 Token
23/iv/46	33·6	{14·0 (Lower) { 1·4 (Upper)	10	3·7 Token
9/v/46	32·2	{18·0 (Lower) { 2·0 (Upper)	10	5·0 Token
25/v/46	98·0	{24·0 (Lower) { 5·0 (Upper)	10	2·2 Token
22/vi/46	146·0	{24·0 (Lower) { 3·0 (Upper)	10	1·46 Token

*Token dosages were introduced above an isolated waterfall about 6 miles up-river from main dosage point at very reduced concentrations.

TABLE IV.

DDT Dosage Record, Tributaries II and III of Kitare River.

Date	Cusecs	Quantity of 10 per cent. DDT Emulsion	Parts DDT per million of water
26/iii/46	Dry	—	—
26/iv/46	0·5	0·5 galls.	17·3
8/v/46	0·5	0·5 ,,	17·3
27/v/46	1	2 ,,	34·6
21/vi/46	1	1·5 ,,	25·95

Assessment of Results.

Two criteria were used to ascertain the success of the experiment, the first and less satisfactory was the absence of immature stages of SIMULIIDAE and the second was the disappearance of *S. neavei* adults. If none of the latter were found for a period of six months, it was thought that elimination, for practical purposes, could be regarded as proven. Observations were therefore made with these criteria in view.

A few days before the DDT was first applied, the rivers were examined in order to select larval and pupal check stations. Three were chosen on the Sanda, five on the Kitare and one on the Awach just below their confluence. All exhibited a high infestation, on the rocks and grasses, of the immature stages of various species of *Simulium* (*alcocki*, Pomeroy, *lepidum*, De Meillon, and *elgonensis*, Gibbins).

Four to nine days after the first treatment, larvae of these species had disappeared completely from all stations with the exception of " C " on the Sanda which was below a stagnant stretch of the river. The number of pupae had decreased to less than a half and whereas there were 72 per cent. of emergences from pupae (92) collected before the application, there were only 19 per cent. (from 47 pupae) after it. Eleven days later, all pupae had entirely vanished except at " C " on the Sanda.

Searches were continued at weekly intervals for five months with completely negative results except at "C", whilst the Kitare above the point of application produced large numbers of larvae and pupae. Special searches were made at points between the routine stations and no *Simulium* were found. The apparent inefficacy of the treatment at station "C" was almost certainly the result of the deposition of the insecticide in the sluggish water upstream. Neither a big increase in the concentration at the dosing point nor the additional introduction of DDT at a place close to "C" itself, had any effect on the *Simulium* at this point. With the advent of heavy rain in the second week of April, the Sanda began flowing much faster and "C" became free of *Simulium* almost immediately afterwards.

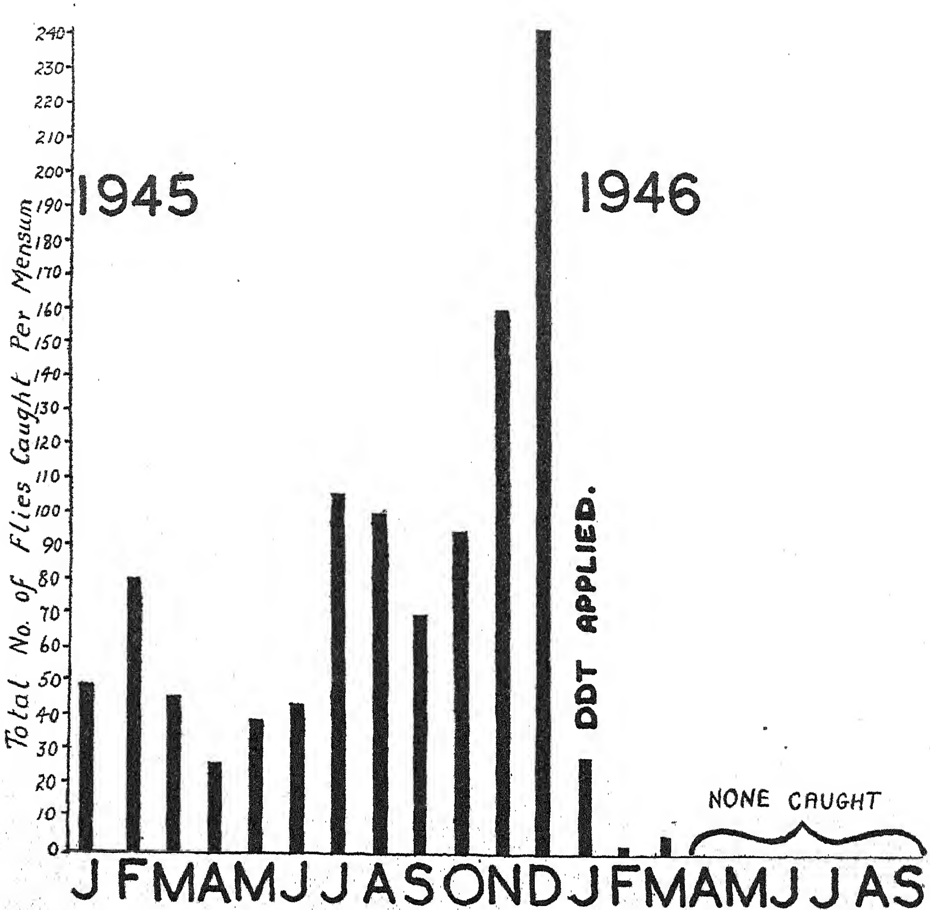

Fig. 3.—*S. neavei*. Adult density at Kodera. Results of routine catches of the adult fly on the banks of the rivers before and during the experiment.

These results indicated the satisfactory progress of the experiment as far as other species of *Simulium* were concerned. The critical point was of course to discover whether *S. neavei* itself had disappeared. Incidentally such a discovery would confirm that this species was breeding in the actual reaches of these rivers. Table V and fig. 3 give the results of routine catches of the adult fly on the banks of the rivers before and during the experiment.

TABLE V.

Adult *S. neavei* Density on Sanda and Kitare Rivers (and Riana as partial Control).

Month	1945	1946	(1946, Riana)
January	48	27	39
February	79	2	38
March	46	5	11
April	25	Nil	4
May	38	Nil	33
June	43	Nil	45
July	104	Nil	24
August	100	Nil	21
September	69	Nil	
October	94		
November	158		
December	240		

DDT applied first on 19/i/46

Standard half-hour catches of one boy in ten catching stations, approximately 20 "Fly Boy Hours" per mensem.

It was impossible to institute a control in the same locality because of the danger of infiltration from an untreated to a treated area. Fortunately, routine catches of the fly were being made at a place six miles away, in connection with Dr. J. C. Buckley's work, and he has kindly allowed his figures to be used as a control. They are not entirely satisfactory as they show the influence of other anti-*Simulium* measures, but they serve to indicate that there was no natural disappearance of fly during the course of the experiment. The figures are given in the last column of Table V.

Table V demonstrates the complete disappearance of *S. neavei* in Kodera after March, 1946. The last fly was caught on 23rd March. Although in 1945, some seasonal fluctuations in numbers occurred, the fly never disappeared. McMahon's figures (McMahon, 1940) for 1939 also showed the high density of fly normally existing in this locality at the same time of the year.

Such routine searches, though interesting, could not of course be regarded as proof of the eradication of *S. neavei* and special intensive searches were made in order to arrive at a definite conclusion. These were made by using up to 12 African Assistants and the results are given in Table VI.

TABLE VI.

Intensive Searches for *S. neavei* adults, Kodera.

Date	Number of European supervisors.	Number of African catchers.	Number of boy-hours per search.	Number of *S. neavei*.
31/i/46	2	6	24	1
9/ii/46	2	10	20	2
12/ii/46	2	6	18	1
17/ii/46	2	8	12	Nil
3/iv/46	1	6	24	Nil
13/iv/46	1	6	24	Nil
11/vi/46	3	12	24	Nil
9/viii/46	1	3	4·5	Nil
September, 1946 ...	3	10	210	Nil

Very careful searches thus failed to produce a single fly over a period of six months (during the latter half of which no DDT had been applied to the rivers). The absence of the insects was confirmed by many Africans living in the vicinity, who used to be much troubled by them and who now state that none is to be seen.

Effect of DDT Applications on other Animal Life.

The first confirmation of the efficacy of DDT treatment was an agitated report from the local inhabitants that fish were dying in large numbers. A little later, however, they came and asked when the next application was to take place. They found it such an easy way of getting fish !

In June 1946, the Kitare River was examined for signs of macroscopic animal life, and snails on the grasses, leeches, crabs and one mud-fish were found, whilst dragon-flies were numerous flying above the river. By September, however, aquatic larvae of the following insects had returned in abundance :—Ephemeroptera (may-flies), Odonata (dragon-flies), Heteroptera, Hydrometridae, Corixidae (water-boatmen), Gyrinidae (whirligig beetles), and Culicidae (*Anopheles funestus* and *A. natalensis*). By September also the Sanda had become re-infested with *S. alcocki*, and it must be assumed that this occurred either by oviposition by flies patrolling downstream from the upper untreated reaches or by larvae being washed down. There was no fear of *S. neavei* creeping back in this way, because it has never existed up-stream above the dosing points.

Discussion.

The experiment has demonstrated the complete disappearance of *S. neavei* adults from a previously heavily infested area of 65 square miles. No fly has been recovered for a period of six months and although it is probable that observations should be continued for several years in order to make certain that *S. neavei* has been completely eradicated, from a practical point of view the experiment may now be regarded as successful.

The value of negative evidence obviously depends in this case upon the efficiency of the catching teams. Their ability to catch biting insects is well illustrated by the impressive list (Appendix) of mosquitos caught in the course of intensive *Simulium* searches and by the large numbers of *S. neavei* they can actually catch in places where this insect still exists. For instance, they collected 126 *neavei* in 20 boy-hours at Kaimosi ; in the previous week, they failed to catch a single one in over 200 boy-hours at Kodera. In the final stages of the experiment, a reward of two shillings was offered for every *S. neavei* collected, but none was forthcoming.

The opinion is held that re-infestation of the area is most unlikely. It could presumably occur in one of two ways : a long surviving adult might start the cycle afresh, but the prolongation of the applications of DDT to five months, *i.e.* three months more than the probable life of the fly, makes this possibliity remote ; or gravid females might be transported to the area by lorry or car, but none of the neighbouring traffic routes runs through any heavily infested district.

The effect on the incidence of onchocerciasis will not be felt until a new generation of Africans grows up ; the absence of microfilaria in young children will presumably be the first result. In order to provide an index for future surveys, 79 children aged 4–8 years were skin-snipped and 29 showed microfilaria (*i.e.* 37 per cent.). Of 14 children aged 3 or 4 years, only one was positive (7 per cent.). Similar age groups in a few years' time should show significant changes.

The details of this method of control will need modification in respect of the minimum lethal dose of DDT, the maximum interval between the applications and the total period necessary to ensure eradication.

The method has apparently the three following disadvantages :—

1. The destruction of fish. The rivers are likely to become restocked later from fish at present existing in the upper untreated reaches and their temporary loss is a minor nuisance compared with freedom from onchocerciasis.

2. Very large rivers would require enormous quantities of insecticide.

3. Deposition of DDT in slowly moving waters. The presence either of swamps or of semi-stagnant, level stretches in the dry season, is likely to interfere seriously with the passage of DDT. Multiple dosing points should be the answer to the former and dosage at the end of the wet season is the solution to the latter.

Acknowledgements.

We have to thank the Director of Medical Services, Kenya, for permission to publish this paper and Mr. C. Y. Carstairs of the Colonial Office, and Mr. A. J. U. Bull of the East African Industrial Management Board for supplies of DDT emulsion.

Summary.

1. An onchocerciasis area in South Kavirondo, Kenya Colony, 65 square miles in extent, has been freed from *Simulium neavei.*

2. The fly was eliminated by the periodical application of DDT emulsion to all infested rivers and streams in the locality. Details of technique are described.

3. Most aquatic life, other than this species of *Simulium*, had returned to the treated streams, three months after the last application.

4. A microfilaria index of 37 per cent. in children aged four to eight was established as a base-line for future surveys.

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APPENDIX.

Adult Mosquitos caught in Riverine Bush, Kodera.

The catches were made in the course of the intensive *Simulium* searches, referred to on page 626, in the months of June and September, 1946.

Species	Number caught	Remarks
Anopheles (M.) gambiae, Giles	1	Male; resting on foliage.
Megarhinus brevipalpis, Theo.	1	,, ,, ,,
Uranotaenia sp.	1	All females.
Aëdes (F.) ingrami, Edw.	46	,, ,,
Aëdes (S.) africanus, Theo.	193	,, ,,
Aëdes (S.) apicoargenteus, Theo.	193	,, ,,
Aëdes (S.) metallicus, Edw.	1	,, ,,
Aëdes (A.) cumminsi, Theo.	64	,, ,,
Aëdes (B.) lineatopennis, Ludl.	75	,, ,,
Eretmapodites chrysogaster, Grah.	1	,, ,,
Culex (Culiciomyia.) nebulosus, Theo.	1	,, ,,

A CHALCIDOID EGG-PARASITE OF AN AUSTRALIAN BUPRESTID.

By Ch. Ferrière, D.Sc., F.R.E.S.

Museum of Natural History, Geneva.

In the course of a study of the biology of the Buprestid, *Prospheres aurantiopictus*, Cast., in Australia, Mr. A. R. Brimblecombe has obtained from the eggs an interesting small Chalcid belonging to the family Encyrtidae.

Several Encyrtid parasites of insect eggs are already known. In Australia *Ovidencyrtus pallidipes*, Girault, parasitises Reduviid eggs, *Tetracnemella megymeni*, Dodd, and *T. hyalinipennis*, Dodd, Pentatomid eggs, and *Cheiloneurus viridiscutum*, Girault, has been bred from those of cockroaches. In Hawaii the genera *Ectopiognatha*, Perkins, and *Fulgoridicida*, Perkins, are found parasitising the eggs of Homoptera. In addition *Leefmansia bicolor*, Waterston, has been bred from the eggs of the Orthopteron, *Sexava* sp., in Amboina and *Leurocerus ovivorus*, Crawford, from the moth, *Amathusia phidippus*, L., in Java. But most of the Encyrtid egg parasites belong to the genus *Ooencyrtus*, Ashmead, and it is among them that is placed the only other species known to breed in the eggs of a Coleopteron, *Ooencyrtus batocerae*, Ferrière, from Malaya. Another species, *Tyndarichus rudnevi*, Nowicky, is said to have been obtained from the eggs of *Cerambyx cerdo*, L., in Russia, but as the species of *Tyndarichus* are generally considered to be hyperparasites, the real parasite of this European Longicorn is still uncertain.

Girault has described six species of *Ooencyrtus* from Australia, in all but one case, from a single female caught in the forest. The only species obtained by breeding, *O. metallicus*, Gir., comes from the egg-masses of *Tara tephrosis*. The parasite of *Prospheres* differs distinctly from all these Australian species and, as it is the only known parasite of Buprestid eggs, it is described here as a new species.

Ooencyrtus prospheris, sp. nov.

♀♂ Black, slightly cupreous on thorax and abdomen and dark green on the face. Antennae entirely black. Legs dark, knees, tibiae at apex and tarsi yellowish.

♀ Head transverse, the face inflexed. Antennae inserted a little below the middle of the face; scape short, oval, pedicellus slightly longer than broad, funicle joints shorter than the pedicellus, subquadrate, the last two a little broader than long;

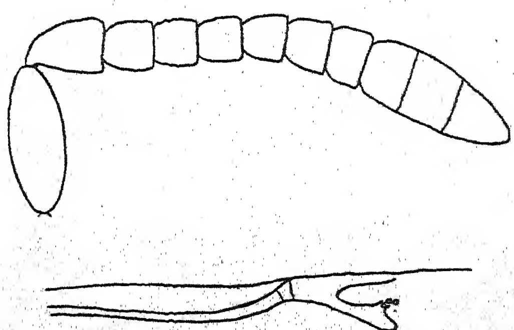

Fig. 1. *Ooencyrtus prospheris*, sp. nov. Antenna and wing nervature.

club not broader than the funicle, about as long as the four preceding joints together. Thorax short, oval, almost flattened above on dried specimens; mesonotum and scutellum finely reticulate-striated, dull; pronotum much transverse, almost as broad as the mesonotum, which is itself more than twice as broad as long; scutellum rounded behind; axillae narrow, their inner angles shortly but distinctly separated; propodeum shining, very short, with a median carina. Wings hyaline, reaching beyond the tip of the abdomen; marginal vein situated at about the middle of the anterior margin, a little longer than broad, about as long as the postmarginal and the stigmal veins. Before the oblique hairless line the ciliae are a little larger and less dense than on the rest of the wing; marginal ciliae very short. The spur of the middle tibiae is as long as the metatarsi. Hind femora and tibiae slightly flattened. Abdomen short, narrower than the thorax, about twice as long as broad. Ovipositor shortly protruding.

♂ Similar but smaller, the antennae longer, with the funicle joints covered with short ciliae, the first joint longer than the pedicel and narrower, the following joints progressively shorter and broader, the last subquadrate; club a little longer than the two preceding joints together. Abdomen shorter than the thorax.

Length: ♀ 0·9–1 mm.; ♂ 0·7–0·8 mm.

Australia : Queensland, Imbil, xii.1943, 5 ♀ 2 ♂ (*A. R. Brimblecombe*).

Type in the British Museum.

In Girault's key of the genera of ENCYRTIDAE (Mem. Queensland Mus., **4,** 1915, p. 120: tribe Encyrtini), this species would run to the genus *Schedius*, Howard, as the axillae are distinctly separated. But it has already been shown that the axillae may be more or less connate or separated in near related species and that this character is insufficient to distinguish two different genera. Therefore *Schedius*, How., is considered a synonym of *Ooencyrtus*, Ashm. (Ferrière, Bull. ent. Res., **22,** 1931, p. 282).

This new species may be distinguished from all other Australian species described by Girault under *Ooencyrtus* or *Schedius* with the aid of the following key:—

Ooencyrtus spp. from Australia.

1. Forewings with a dusky cloud below the marginal vein................................2

—. Forewings hyaline 4

2. Head and thorax metallic purple with greenish tinges. Antennae yellowish white with the last funicle joint blackish........................*metallicus*, Gir.

—. Head orange-yellow or golden...3

3. Thorax dark metallic blue, abdomen coppery with the sides and venter orange-yellow. Antennae whitish, pedicel and 6th funicle joint black. Funicle joints all wider than long, except first quadrate; club about three-quarters the length of the funicle....................................*bicolor*, Gir.

—. Thorax and abdomen grass green. Antennae dusky, scape pale yellow. Funicle joints wider than long, except the 6th larger; club as long as the funicle...*auricaput*, Gir.

4. Legs white, except coxae and sometimes a ring on hind tibiae........................5

—. At least hind legs mostly black..6

5. Hind tibiae with a broad dark ring extending from near the knees to the middle. Funicle joints wider than long, 5th and 6th larger, the 6th nearly twice as broad as long....................................*unicinctipes*, Gir.
—. Hind tibiae entirely white. Funicle joints 1 to 3 quadrate.................... *magnioculos*, Gir.
6. Middle legs and front tibiae yellowish, hind legs dark, except apex of tibiae. Funicle joints 1 to 4 about twice wider than long, 5 and 6 nearly twice longer; club longer than the funicle...................*magnithorax*, Gir.
—. Legs black, only knees and apex of tibiae yellowish. Funicle joints 1 to 4 subquadrate, 5 and 6 a little broader; club shorter than the funicle...*prospheris*, **sp. nov.**

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